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IMPLEMENTING AUTOMATED ROAD TRANSPORT SYSTEMS IN URBAN SETTINGS

Edited by Adriano Alessandrini

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Edited by

ADRIANO ALESSANDRINI

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To my muse

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CHAPTER 1

Introduction

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CHAPTER 1.1

CityMobil2 an EC Funded Project

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1.1.1 THE PROJECT AND ITS SELECTION

CityMobil2 was a large-scale integrating research and demonstration project cofunded by the Directorate General Research and Innovation of the European Commission within the Seventh Framework Programme for Research and Development (FP7). Its total budget was of 15.5 M€ with a total EU contribution of 9.5 M€.

As any EC-funded project, the consortium prepared a proposal to answer a competitive call for proposals issued by the European Commission. CityMobil2 was evaluated by a panel of independent experts and then selected by the European Commission for funding. The winning aspect of the proposal, back in late 2011 to early 2012, was the ability of the consortium to integrate fully automated vehicles on urban roads sharing the road (with certain limitations) with conventional vehicles and other road users.

The project was coordinated by Professor Adriano Alessandrini first at the University of Rome La Sapienza and then at the University of Florence for the last project year. The project was composed by an impressive consortium of more than 45 partners including 12 cities and 5 vehicle manufacturers. During the project, a few of the manufactures withdrew or went bankrupt, and new born ones had to be added. As described in the next section, it is the flexibility of the work plan and of the resource allocation, which kept the project on track and allowed it to deliver.

1.1.2 A FLEXIBLE DESCRIPTION OF WORK AND RESOURCE ALLOCATION

CityMobil2 is the eighth in a stream of EC-funded research projects in the field that helped in building the technologies and the know-how in the last 15 years to bring fully automated road transport safely on the road: CyberCars, CyberMove, NetMobil, EDICT, CityMobil, CityNetMobil and CATS. The predecessor project CityMobil, though very successful, did not demonstrate fully automated vehicles on mixed urban roads. Its key demonstrations were the personal rapid transit (PRT) at Heathrow Airport in the United Kingdom and

the bus rapid transit (with reserved way and driver on board) in Castellon de la Plana in Valencia region, Spain. The two originally selected demonstrators never took place, and all demonstrations (including a final small demonstration with prototype vehicles in La Rochelle, France) were replacements to the originally proposed ones. CityMobil started raising the interest of the cities for this kind of transport systems, and thanks to POLIS (the European city network), cities started getting interested in the project. Thus, a second stream of much smaller demonstrations, named showcases, were organised for cities not members of the consortium, which followed its results and proposed interesting applications. This group of cities was called the 'reference group'. The initiative was such a success that the EC decided to fund another small project to extend the activity with the CityNetMobil. CityNetMobil used the prototype vehicles of INRIA (the French national research centre that started it all 20 years previously) and organised a continuous selection process between cities to keep them motivated.

Learning from these experiences, the CityMobil2 work plan was organised in a flexible way with two selection phases: one for the vehicle providers and one for the demonstrations. Two fleets were to be acquired from the project and brought for a period of 6 months in five European cities.

The project was organised in two phases: the first one of 18 months is to

- define the technical specifications for the transport systems;
- define the urban integration principles;
- define the manufacturer and the city selection methodologies;
- have cities carry out a study each;
- have manufacturers prepare a proposal each;
- at month 18, select two vehicle manufacturers and five cities.

The second phase, 30 months long, was to be dedicated to the five demonstrations and the five showcases.

Two contract amendments were foreseen to reallocate the budget and responsibilities.

For the selection of the demonstrations and showcases and in order to guarantee a strict monitoring over the selection process, the EC reviewers were involved in the selection processes during the periodic project reviews.

This extreme flexibility together with a tight control of the resource transferred proved to be the key of the project's success. One of the two selected manufacturers went bankrupt and had to be changed. The demonstrations were often of different duration (e.g. in Vantaa, Finland, it was for a housing fair for a few weeks, and in Oristano, Italy, it was for the summer season); thus, rather than five large demonstrations, the project decided to go with seven demonstrations with three large ones and four smaller ones.

1.1.3 THE SELECTION OF THE ARTS PROVIDERS

CityMobil2 was originally organised in 29 work packages (WP).

WP1 defined the site study methodology and site selection procedure.

Work packages from 2 to 13 were dedicated to the city studies.

WP14 focussed on the ex ante evaluation of the city studies and the site selection.

WP15 was devoted to define the technical specifications for the vehicle fleets and then evaluate the technical proposals of the different manufacturers to select the best two.

The first four deliverables of WP15 remain one of the main technical achievements of the project. They defined first the concept of automated road transport system (its evolution throughout the project and final definition is in Ref. [1]) as a combination of vehicles with its localisation and navigation system and obstacle detection, communication system and infrastructures. The four deliverables were dedicated respectively to

- the functional behaviour of the vehicle and their interaction with the infrastructures resulting in the specifications for the infrastructures themselves (D15.1),
- the vehicle positioning, navigation and guidance and control specifications (15.2),
- the specifications for obstacle detection and avoidance (15.3),
- the specifications for the communication architecture (15.4).

None of the deliverables defined technologies. They defined the performances the technologies must guarantee and the tests to measure them.

The process of defining such specifications has been collaborative. The INRIA team (which led the WP) proposed the definitions and the measurement methods, and all the partner manufacturers had the occasions to participate in the discussion and release some of the requests (e.g. some on the range of working temperature have been released). Then, each of the manufacturers proposed a fleet of ARTS (minimum six vehicles and minimum 60 passengers overall) to respond, and the proposals were compared and the two best ones selected.

The winning proposals were those of **Robosoft** and **Induct** both proposing fleets of 6–10 passenger vehicles. Being both small companies, plans to gradually transfer funding upon verified progresses were agreed with each other, and the coordination team organised periodic visits to the factories and the demonstration sites to verify the consistency of the progress.

The manufacturer selection and the city selection (as described below) were ratified with the European Commission periodic review in January

2014. Unfortunately, soon after the review, Induct went bankrupt, and a new manufacturer had to be found. The gradual transfer of funding avoided losing EC funding, which would have jeopardised the project. An intense contact with manufacturers from all over the world (in 2014 the hype of the autonomous vehicle had already started and many more companies had declared themselves ready to roll out automated vehicles). In the end, the second fleet was procured by the newborn company EasyMile joint venture of Ligier car maker and Robosoft. The EZ10 vehicles were conceived to respond to the project specifications.

EasyMile became the second manufacturer, and the European Commission ratified the achievement allowing a second contract amendment.

WP16 and WP17 were to become the demonstration WPs of the two selected manufacturers to procure and manage the two vehicle fleets throughout the project phase 2. CityMobil2 wanted off-the-shelf technology for its ARTS; however, some technological developments were necessary from both manufacturers; thus, both WP16 and WP17 were split in two becoming WP161, WP162, WP171 and WP172.

1.1.4 THE ORGANISATION OF THE DEMONSTRATIONS AND THE OTHER PROJECT WORK

WP18 remained dedicated to monitoring the technical results and to human factors, but a new partner (Vislab with its 3D Cameras) was added to measure the reactions of people around the fully automated vehicles.

Work packages from 19 to 23 were dedicated to the demonstrations, WP24 to showcases;

WP25 focussed on the ex post evaluation, WP28 to dissemination and WP29 to management.

The two other main goals of CityMobil2 were

- to define **legal framework** to mix automated and manually driven vehicles (this was done in WP26);

  to **forecast long-term impacts**, which was the objective of WP27.

1.1.5 THE SELECTION OF THE DEMONSTRATION CITIES AND SITES

Within the selected cities, 12 partner cities had agreed to investigate the possibility of installing in one or more local sites ARTS. Documents were provided to cities to explain what was feasible with ARTS and what was not and to guide them to collect comparable data and make comparable studies.

The studies (a thorough comparison of the ex ante studies is provided in Ref. [2]) were compared and the most promising sites for demonstrating ARTS selected.

Selecting the sites was a scheduling exercise. Rather than selecting all the sites immediately, a different approach was followed: the first demonstrators (Oristano, Italy; La Rochelle, France; Lausanne, Switzerland; and Milan, Italy) were selected, and the others were kept open for later. The European Commission approved the choice in January 2014 review.

Then, in February 2014, the bankruptcy of Induct affected the scheduling of the demos. In summer 2014, Milan, which had been selected to receive both fleets from May 2015 to November 2015, withdrew freeing the fleets for more demonstrations.

It was then possible to increase the duration of the demonstration in Trikala and add two further demonstrations sites in Sophia Antipolis, France, and San Sebastian, Spain.

In the end, demonstrations of ARTS fleets took place in **seven cities from six different European countries**:

- Oristano, in Sardinia (Italy), in July and August 2014 [3]
- La Rochelle (France) from October 2014 to April 2015 [4]
- Lausanne (Switzerland) from December 2014 to August 2015 [5]
- Vantaa (Finland) in July 2015 [6]
- Trikala (Greece) from August 2015 to February 2016 [7]
- Sophia Antipolis (France) from March to May 2016
- San Sebastian (Spain) in from April to July 2016 [8]

1.1.6 THE CityMobil2 KEY SUCCESSES

Besides conducting the demonstrations carrying more than 60,000 passengers in urban environment, CityMobil2 was extremely successful in

- demonstrating that road automation (full automation) is feasible today;
- demonstrating how to prepare the urban infrastructures to allow simple and safe technologies to operate fully automated road transport [9,10,11];
- defining a procedure to certify infrastructures and technologies to achieve a desired level of safety [12,13];
- predicting how policies are needed at this stage to steer developments to achieve positive long-term impacts [14].

Besides these already outstanding successes, the unprecedented result for a European research project is the incredible number of cities all over the world now experimenting similar technologies and solutions and to have

'started' the 'shuttle' industry. This is however also a risk because the shuttle themselves do nothing if not carefully inserted in an integrated approach as done in CityMobil2 demonstrations.

1.1.7 THE FUTURE

CityMobil2 could demonstrate that innovative automated road vehicles could run in several European cities, even in mixed traffic conditions, making tests for several months. Of course, in some countries, the presence of an operator was mandatory on board the vehicles, but CityMobil2 could also make a proposal for changing the legal framework in several member states.

In addition, this was the only project of that nature in Europe and even in the world. Discussions and exchange of information took place with other countries like the United States and Japan where CityMobil2 was seen as a reference.

For the future, before going for a full deployment of automated vehicles on our roads, there are still some challenges to be tackled:

- Demonstrating reliability, safety and robustness of technology
- Harmonisation of the legal and regulatory framework
- Users' and societal acceptance
- Common validation procedures and testing requirements
- Infrastructure requirements (including the links with connectivity)

Research and development and large-scale field operational tests (FoTs) are still necessary. That is why, within the Horizon 2020 work programme 2016–17, there is for the first time a specific call in 'road transport automation' with a budget of 114 M€ and with emphasis on large-scale field operational tests and demonstration pilots for cars, trucks and fully automated urban road transport systems. The call text recognises that member states may need to adapt their regulatory framework to enable these trials.

Within the 2017 call, there is a dedicated topic, ART-07-2017 'Full-scale demonstration of urban road transport automation' that was launched in early 2017.

Whether the resulting project(s) will prove as successful as CityMobil2 is too early to say, but it is clear that these are the moments in which the future of urban mobility, transportation industry and even vehicle industries will be shaped for the next 20–50 years.

Very recently, the developments of automated vehicle pilots are emerging around the world. Today, most of these pilots are small scale and involve either on-demand ride services or low-speed shuttles operating in controlled environments.

For the future, shared, connected and cooperative automated vehicles may become a game changer for urban mobility. They can provide seamless door-to-door mobility of people and freight delivery services, which can lead to healthier, more accessible, greener and more sustainable cities, as long as they are integrated in an effective public transport system. European citizens will not anymore buy cars for their urban trips but mobility services.

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CHAPTER 1.2

ARTS—Automated Road Transport Systems

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1.2.1 INTRODUCTION TO ROAD AUTOMATION

The growing visibility on media of advanced driver-assist system trials following the Google publicised research programme on the matter and the enthusiastic announcements of some OEM leaders have led many to believe that fully automated cars will be deployed on roads around year 2020.

However, people working to automate cars have, in most cases, very different views. *Electronic chauffeurs that can handle any driving conditions with no human input are decades away* according to Shladover [1].

The divergence in views is caused by a taxonomy confusion. OEM have started (after Google) using the term 'autonomous' vehicle for any kind of driver-assist system (like those now available in Tesla and called by Tesla Autopilot), thus creating the expectation of a car that can drive itself but delivering instead a vehicle that require presence and engagement from a driver.

SAE defined five automation levels (or better six including zero) in its standard J3016 [2]:

0 No automation
1 Driver assistance
2 Partial automation conditional
3 Automation
4 High automation
5 Full automation

SAE puts a key distinction between level 2, where the human driver performs part of the dynamic driving task, and level 3, where the automated driving system performs the entire dynamic driving task. Such distinction is needed mostly for legal purposes. While up to level 2, the driver is 'in control' of the vehicle and therefore entirely responsible for it from level 3 on, at least on some infrastructures and for certain time periods, the driver is no longer 'in control' and therefore legislations need to be updated.

Another key distinction, though not highlighted by the standard itself as the previous, is from levels 3 and 4 on one side and level 5 on the other. Level 5 implies, by definition, its applicability everywhere, while level 3 and 4 functions can be restricted to certain infrastructures and geographical areas.

In this light, US DoT and NHTSA in drafting the US Federal Automated Vehicles Policy [3] has included operational design domain (ODD), thus implying that some automation functions can only be usable in certain predefined conditions and infrastructures and not everywhere.

So, the OEM agreed upon a roadmap in which driver-assist systems will progressively relieve the driver from driving task up to eliminating it. In such a roadmap, the role of infrastructures is never discussed, and it is generally assumed that the progressive automation of the driving will not require any modification of the driving environment.

A different roadmap has been proposed since proposal stage by the CityMobil2 project; it moves from automated people movers (APM) and automated metros, which are operational for decades but with different levels of segregation, reducing to 'nothing special' the infrastructural modifications in the highest levels. Automated metros are (most of the times) fully segregated with a protected way and platform doors, but people mover can be less hardly segregated. The Rivium ParkShuttle of 2GetThere, for example, has its own way, but it has intersections at grade, and sometimes (even if they should not be allowed), cyclists and pedestrians use the shuttle way.

How the two roadmaps and how they converge a chart can be drafted. On two axes, there are automation levels (from nothing to full according to SAE levels [2]) and on the other axe the 'segregation' level of the infrastructures [4]; the OEM roadmap moves from no automation to full automation always with no segregation, while the CityMobil2 project believed in full automation from the start in progressively more open environments.

The two roadmaps converge only to level 5 when the vehicles are fully automated everywhere (as shown in Fig. 1.1 of the papers [5,6]). However, the introduction of the ODD concept for the 'autonomous' cars has made the roadmaps converge earlier. In Fig. 1.1, the roadmaps are reviewed to reflect these changes.

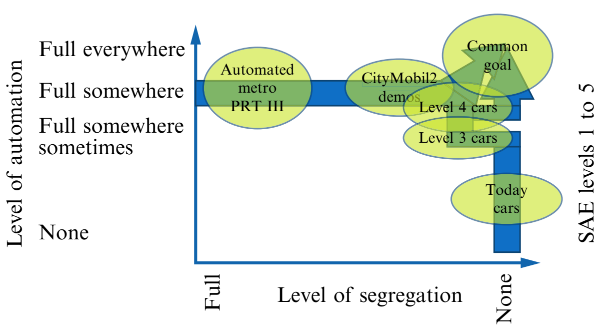

Fig. 1.1 Converging roadmaps to full automation.

SAE levels 3 and 4 are no longer 'everywhere' and were never 'anytime'. Thus, a fully automated APM vehicle (which is fully automated only on certain infrastructures) is already a level 4 on the other roadmap as soon as APM vehicles get out of full segregation and 'hit the road'.

Besides the earlier convergence, the most important point of this change is the introduction of infrastructures in the approval procedure of vehicles (automated road vehicles). The automated vehicles (at least at levels 3 and 4) can only be approved alongside the infrastructures.

This moves the vehicle from being autonomous (if it ever were) to become part of a transport system that include the infrastructures.

This does not include yet communication, but communication is essential to have safety and capacity at the same time.

1.2.2 COMMONALITIES AND DIFFERENCES BETWEEN ARTS AND AUTONOMOUS VEHICLES

The key difference is that ARTS are conceived to perform one certain transport task, from somewhere to somewhere else using known paths on the known infrastructures, while autonomous vehicles can (in principle) go anywhere.

This has immediate behavioural implications of autonomous vehicles.

- They need to continue to work even when something is malfunctioning, thus needing redundant energy supply and redundant actuators, and basically they need to guarantee that even if they are not in a condition to proceed, they are capable (on any infrastructure and traffic situation) to reach a safe stop condition.
- They need to detect everything on their own without relying on any cooperation with infrastructures or other vehicles; an often used example is the needed capacity to detect the roadworks ahead or eventually policemen and school busses so to change their behaviour accordingly.
- They need to predict other user behaviours as a human driver would do.

Though the technologies to respond to these needs are amazing and are fuelling a race between tech industries, they are useless for ARTS and, at least in the first stage, very dangerous because technology failure can lead to disasters.

ARTS behaviour is completely different.

- ARTS need a certified lane (following the technical approach described in Refs. [6,7] and applied in Ref. [8] and the certification procedure described in Ref. [9]) with dedicated aspects in the light cycle and some protection depending on the speed of the flow as explained in Refs. [6,7].

- Other vehicles are allowed on the ARTS certified lane if they respect some rules: no stopping, no parking and no overtaking.
- ARTS vehicles do not predict any user behaviour; at design stage, all threats are assessed and countermeasure taken to guarantee safe proceedings for the vehicles. They only need to verify continuously the distance to moving and fixed obstacles and adapt the speed to avoid even the possibility of a crash.
- In intersections, the threat posed by vehicles on potentially conflicting paths is lowered embedding sensors in the infrastructures to detect wrongdoing and preventing accidents or forcing other vehicles to lower speed.
- The ARTS vehicles do not need to detect schools—they know a school is there—or roadworks; the control room is informed of roadworks and plans the detours in advance, and policemen can have a remote control to be recognised by ARTS vehicle or simply call the control room.
- Redundancy is needed much less, because a fail-safe approach is adopted. Brakes and steering are preactuated (as in APMs), and the loss of power or a failure would simply trigger an emergency deceleration for the vehicle to come to a safe stop on its trajectory.

Autonomous vehicles need a lot more interesting technology and once it will be available a lot more testing, while ARTS are here now and are ready to be deployed as demonstrated by CityMobil2.

1.2.3 DEFINITION OF ARTS

Automated road transport systems are systems, not only comprising vehicles but also comprising infrastructures, control systems (including communication, remote supervision and roadside sensing) and the vehicles themselves.

ARTS vehicles are far from being autonomous; they do not take any decision; at design level, decisions have been taken from them, and should there be the need of an exception to the preprogrammed behaviour, the human supervisor needs to authorise the exception remotely from a control room.

The technology is much simpler (and safer). The vehicles need to follow a predesigned (and certified) trajectory with a precomputed driving cycle. Variations to that are only consented to slow the vehicle when a moving obstacle is close or stop in case it is on the collision course.

This is implemented creating two dumb safety areas.

The first, the emergency area, is in front of the vehicle, as large as the vehicle and as long as the deceleration space at emergency deceleration and

the given speed (thus, its length changes with the speed). The presence of any object large enough in this area triggers the emergency brake. This is a low-level function; a simple switch as such this final safety is never affected by communication or external penetration or intelligence failure (prescription taken by the Machinery Directive 2006/42/EC) making the system safer than any other on the street.

The second safety area extends in front of the vehicle, on its sides and on its back. If any moving obstacle is detected too close to the ARTS vehicle, the vehicle slows down. This is the case when a pedestrian walks on the vehicle side or a cyclist rides in front of it. In one case, the vehicle will overtake the pedestrian (because she walks out of the vehicle path) but at a reduced speed that would allow even when the pedestrian suddenly changes direction or falls not to hit her. In the second case, the vehicle will follow the cyclist adapting its speed and keeping at a distance from it should it fall or brake suddenly. The ARTS vehicle will not overtake the cyclist unless the cyclist exits from the vehicle path.

This requires at design stage to clearly mark on the road the path of the ARTS and to decide when vulnerable road users are allowed to share ARTS lanes because their presence would slow the vehicle operation as safety imposes.

In this second larger safety area, the moving object classification (as pedestrian, bikers or other) and their path tracking are suggested but not mandatory. Tracking would help in deciding how to intensely decelerate but would never be used to forecast the other road user behaviour; ARTS simply assume the worst possible behaviour and prepare itself to cope with it.

As this extreme attention to safety risks jeopardise performances, certain rules must be respected for other road users to share ARTS lanes. For example, cars can be allowed on ARTS lanes, but they need not to stop, to overtake or to follow the ARTS vehicle too closely. If the vehicle preceding the ARTS vehicle stops, the ARTS vehicle cannot overtake it. If the vehicle overtaking the ARTS vehicle re-enters the ARTS trajectory in the ARTS vehicle safety area, it would cause the ARTS vehicle to emergency brake. If a brick-wall stop safety distance is not respected, the ARTS vehicle would slow down to prevent being rear-ended in case of emergency brake. These are the reasons behind these simple rules; they are always centred on safety.

The ARTS is therefore composed of

- the vehicles, which follow the behaviour just described and feature a simple yet effective technology;
- the infrastructure, which is conceived to maximise safety and certified for the specific vehicle to use safely;

- the control system, which has a control room in contact with all vehicles at all times, establishing tasks for the vehicles and priorities on infrastructures; a human supervisors who can intervene in case of need is always in the control room.

The infrastructures have been defined already in Ref. [5]; here, a slightly modified definition is given to reflect that even reserved infrastructures can be shared under certain rules.

Infrastructures can be organised in three levels lane-sharing for ARTS:

- segregated—in which ARTS vehicles are the only ones allowed and the lane is physically protected against external intrusions;
- dedicated—in which the lane used by the ARTS is clearly marked to be used preferentially by the ARTS vehicles, though other users can access it but need to respect certain rules;
- shared—in which ARTS, manual vehicles and other road users share the same lane without any precaution.

Segregated lanes are not simply reserved to ARTS vehicles; they are protected against external intrusion allowing high-speed operation (just like motorways). In dedicated lanes, even if the ARTS vehicle has priority, pedestrians and bikers can cross them and move on them, and other vehicles can be allowed if they respect few basic rules (no overtaking, no parking, no stopping and no reducing the distance from the ARTS vehicle below safety distance). CityMobil2 didn't envisage shared lanes in the project's demonstrations. However, they can be foreseen in the future.

1.2.4 THE LAST MILE ARTS DEMONSTRATED IN CityMobil2

Though ARTS can potentially be used everywhere in cities, they are conceived to complement mass transits, and the Achilles' heel of public transport is last mile. By automating last-mile transport, the entire public transport chain becomes more attractive.

CityMobil2 has started deploying ARTS for last-mile on-demand services.

However, a number of issues starting from legal to the use of land to political had to be negotiated in each site, and the demonstrated ARTS

- were never on demand (with the exception of a test in Lausanne demo [10]),
- always followed a single line rather than a network,
- were last mile from the metro station to a campus in Lausanne [10] and last mile to bring people to a housing fair in Vantaa [11] and tried and

failed to be the last mile from the train station to the harbour in La Rochelle but could not reach the station [12].

The control room with remote drivers was implemented in Trikala [13] and Lausanne [10] but not elsewhere.

Other temporary systems, human-intensive, have been used in CityMobil2 to guarantee safety and supervision.

1.2.5 THE FUTURE OF ARTS INTEGRATED WITH ALL TRANSPORT MODES IN CITIES AND OUT

The future of ARTS starts from CityMobil2 but will grow to city level and out of the 10-passenger shuttle concept so many today identify with CityMobil2.

As explained by the project officer in Ref. [14], the selection of shuttles with 10-passenger capacity was due to a combined need to have at least 6 vehicles per fleet and to move contemporarily at least 60 passengers to have some visible result in terms of demand. Manufacturers were left free to provide 12 vehicles for 5 passengers each, but they all chose 10 passengers mostly to reduce costs.

The future of ARTS will need to cover from 4-passenger vehicles to 50-passenger vehicles depending on the demand.

The vehicles will need to have a shared taxi-like service in the city outskirts where the demand is less intense up to corridors where they will form platoons and reach BRT-like capacities to go to city centres and main network nodes to interchange with existing and innovative systems.

The ARTS will not only cover the last mile but also can be an integrated last-mile long-distance service.

The interesting aspect is that the CityMobil2 demonstrated technology is already sufficient (combined with more traditional ITS ones) to provide such services today.

What is still to be demonstrated is that the envisaged business model can bring public transport out of subsides and in the profit-making realm motivate private investors to invest on it as much as companies are investing in the automated private car.

1.2.6 CONCLUSIONS

Automated road transport systems are made of automated vehicles riding on the roads but are not autonomous vehicles. They share the sensing technology and some intelligence but have huge difference in the philosophical approach that leads to technological differences and to use-case differences.

ARTS are derived from factory AGVs and from APMs and are designed to be as safe as a rail system.

They were demonstrated in CityMobil2 in niche applications of last-mile shuttle services but can be extended to an entire city and beyond getting out of the niches and revolutionising the market.

ARTS are ready to roll today when fully automated autonomous vehicles are far from being.

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CHAPTER 2.1

Dimensioning ARTS for Last Mile Transport

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2.1.1 INTRODUCTION

A dimensioning procedure for the ARTS in the last-mile transport service is reported in this paper.

It has to be used after a preliminary phase, not reported here, regarding the urban mobility planning, where an ARTS is chosen to serve a specific urban area for the last-mile transport. The procedure represents the first step of the three-step ARTS stepping out on the stage of the urban mobility, where the second step is represented by ARTS speed profile definition (reported in the next paper [1]) and the third step is represented by ARTS urban integration, whose general principles are reported in Ref. [2].

The ARTS allows a more flexible service, if compared with conventional transport systems, and could represent a solution for the last-mile transport issue, both in terms of the quality of the service provided and of the costs linked with the service [3]. The service can be modelled on the basis of the demand to be served by the ARTS, in order to be able to serve all the user requests with the on-demand capability, allowing low waiting times (in accordance with user needs) and high vehicle occupancy.

It can represent a strong measure to allow people to leave their private car possession and to shift to a high-quality collective transport.

Starting from this preliminary result, the procedure allows to identify the demand to be served by the ARTS and the consequent origin-destination (OD) matrix for the ARTS user trips and via several dimensioning steps (regarding routes, lists of requests and vehicle occupancy) to choose the vehicles to provide the service and to dimension the fleet to be used, in order to provide a high-quality and flexible service.

The procedure is explained step by step in the next section.

2.1.2 THE PROCEDURE TO DIMENSION AN ARTS FOR LAST MILE TRANSPORT

As reported in the introduction, the dimensioning procedure aims at dimensioning the ARTS fleet to serve a transport demand that is identified at the start of the procedure. Since such demand is estimated for and to be

served by the ARTS, the procedure is part of an iterative process, directly linked with the urban mobility planning. The ARTS service, once operating, could be able to change the mobility modal shares, allowing the shift from the private car to the ARTS itself. In such case, the demand estimated for the ARTS would change, and the procedure should be reiterated in order to dimension the vehicle fleet to serve the new demand.

ARTS dimensioning procedure for the last-mile transport should follow these steps:

1. Identification of the transport demand to be served and OD matrix generation
2. Routing procedure for the identification of the shortest paths to serve the user calls
3. Generation of different lists of user requests
4. First round of simulations
5. Analysis of the possible vehicle occupancy increase through the ride sharing (new routing)
6. Final round of simulations and fleet dimensioning

The six steps are described in the following subsections.

2.1.2.1 Identification of the Transport Demand and OD Matrix Construction

This is the first step of the ARTS dimensioning procedure. It is crucial since it allows to estimate the number of potential users of the system and to locate them inside the different zones to be served. Therefore, it can be divided in two substeps:

1. Demand identification
2. OD matrix definition (based on demand data)

Different techniques can be adopted for the identification of the demand to be served. For example, it could be estimated through specific surveys like those described in Refs. [4,5]. As an alternative, the demand could come from transport census data [6], where available, or it could be obtained through a mixed approach (surveys complementing transport census data).

Once estimated the demand, a preliminary analysis should be implemented to have a first rough spatial classification of the user trips, taking into account the potential sites where the ARTS has to be operated. As shown in Table 2.1, they should be divided according to three categories: inner, ingoing and outgoing. Such analysis allows to simplify the OD matrix generation and, if requested for computations, to divide it into three different matrices, one per category (the call list generation can follow the same category

Table 2.1 Trip categories

Trip classes		Description
A	Inner	People living in the potential site and travelling daily inside it
B	Outgoing	People living in the potential site and daily travelling outside it
C	Ingoing	People not living in the potential site and coming daily from outside it

classification reported here, as it can be seen in Section 2.1.2.3). Furthermore, in case of demand estimation through surveys, it could be useful to cross compare the results with census data (where available) in order to verify if the data obtained are representative of the three different trip categories.

In the OD matrix definition substep, all the transport modes used in the potential site should be included [7], and the OD selection should include both an urban area centroid and a connection point to another transport mode. The size of the OD matrix in terms of number of nodes (i.e. origins and destinations) directly depends on the technique used for estimating the demand. The larger the number of nodes is, the more the problem (and the associated travel costs) is complex. For example, an Italian census agency (ISTAT) provides a commuting matrix including all trips between each Italian municipality, divided per transport mean and travel reason. The census data can represent a good starting point to estimate the transport demand and to generate OD matrix when they are not available in other ways.

The output of this step is the transport demand and the OD matrix (or matrices where needed) of the potential ARTS site.

2.1.2.2 Identification of the Shortest Paths for Each OD Couple

Before detailing this step, the following definitions have to be taken into account:

- **Itinerary**. Route connecting each OD couple, composed of a series of paths, generated with a dedicated algorithm and for which the duration in time and length are defined
- **Path**. Set of continuous road graph arcs composing the itinerary, including intermediate and terminal nodes
- **Routing**. Path scheduling, with defined start and stop time (intermediate and final stops)

The length and travel time of the itinerary depend on the functional characteristics of the paths composing it. These, in turn, depend on the

hierarchical role of each path as identified in the urban planning process. Therefore, the length and travel time of each itinerary depend on the selected paths, and alternative solutions may exist, depending on the urbanistic characteristic of the considered urban area.

For each couple of nodes of the generated OD matrix, a routing procedure is requested to obtain the shortest path or the fastest path. Different algorithms are available and can be used to accomplish this step, as in Refs. [8,9]; these are usually based on simulations or other dedicated tools. As a general rule, the routing should include for each trip:

- Length
- Duration
- List of streets or arcs involved

After a first routing, the analysis of how many times the different arcs are used to cover the shortest paths is needed to define two categories of arcs:

- Main (or preferred) arcs, which are frequently used for almost all the trips
- Secondary arcs, which are used only for a few number of trips (e.g. less than 10% of trips)

The number of arcs for each category is directly linked with the main features of the potential site, such as landing development, mobility policies and arc configurations.

The main arcs are useful to point out on the roads where traffic and congestion could result higher, whereas the secondary arcs are useful in a possible iteration to find the best routing (by reducing the time spent on congested arcs, even if passing on a secondary arc could result in a longer path). A prerequisite for using secondary arcs is the availability of traffic data on the selected arcs, and a post requisite is the safety impact of the solution, taking maximum allowance of the vulnerable road users' safety requirements.

Then, a setup phase is needed to define, after the first analysis, the maximum allowed length and duration of the trips. With such a procedure, the shortest requested paths are obtained as output of this step.

2.1.2.3 Lists of Requests Generation

In order to dimension a vehicle fleet able to serve all the users' requests, the ARTS should be able to serve all the peak-hour requests. Thus, the request lists have to be generated considering the demand during the peak hour. Therefore, the vehicle fleet needed to serve the users' requests during the peak hours will be able to serve the requests during the off-peak hours too.

The generation procedure to be adopted should be random and can make use of Microsoft Excel or any other software, algorithm and/or calculation procedure.

The last-mile ARTS service provided is mainly connected with mass transport modes, for example, the train or the airports. Thus, the generation of lists of requests should take into account external factors like the scheduled arrival and departure times of the other transport modes for those municipalities where people commute daily to and from other municipalities.

In order to consider the different trip categories reported in Table 2.1, the lists of requests can be first divided according to such categories and then merged in case the same timing is requested for some of them.

However, in both cases (one list of requests including all the trip categories or different lists of requests, one per trip category), several random lists of requests have to be generated, as output of this step, in order to allow the iteration of the simulations in the next step.

2.1.2.4 First Round of Simulations

A first round of simulation should be provided starting from the output of the previous steps: demand, OD matrix, shortest paths and lists of requests.

The tools to be used for the simulations can be chosen according to the route complexity and to the degree of accuracy requested. Possible approaches that can be used, starting from a line and going to a network, are, for example,

- calculations based on the network features,
- use of a dial-a-ride problem solution algorithm,
- use of a dedicated macrosimulation tool,
- use of a microsimulation tool.

The output of this step is a first fleet dimensioning, which can include the following data:

- Requested trips served
- Number of vehicles used for the service
- Working time of each vehicle
- Vehicle mileage
- Passenger-kilometre travelled
- Average travel time
- Deviation from the average travel time
- Vehicle occupancy

Starting from such data, the ride-sharing analysis reported in Section 2.1.2.5 has to be done.

2.1.2.5 Ride Sharing Capability Analysis

This step is the core of the ARTS dimensioning, aiming at verifying the ride-sharing capabilities of the system designed in the previous steps and at simulating its operations based on the ride sharing to improve the service.

The first output of the previous step (simulations reported in Section 2.1.2.4) to be taken into account is the vehicle occupancy. In order to improve the number of passengers per vehicle, the spatial and time distribution of the demand has to be analysed. Some requests could be in the same time windows with close (or equal) origin and destination. In such case, the same vehicle could be used to serve them, and the ride-sharing capabilities have to be simulated.

Before explaining the ride-sharing capability analysis procedure, the following definitions of parameters to be used have to be provided:

- **Pool**. Group of people using the same vehicle during a single routing. They can board the vehicle in different times and/or places. For example, a vehicle with a route planned from the point A to point B starts its route in A; then, it reaches two intermediate points C and D to pick up some users and then goes to the destination B and delivers all the users previously picked up.
- **Pick-up/delivery time**. Time spent at the stops for pick-up and delivery of the passengers into the vehicle.
- **Detour time**. Estimated time to be spent for each intermediate stop (other than for picking up and delivering people).
- **Maximum vehicle capacity**. Number of places in a vehicle and maximum allowable people for a pool. It is the core parameter of the fleet dimensioning (see Section 2.1.2.6), and it has to be adapted if during the request list generation many trips happened simultaneously at the same time and/or in the same place. However, the vehicle capacity increasing or decreasing has to take into account other linked variables, such as vehicle costs, possible congestion generated in those paths with highly concentrated requests and people using the vehicles during the peak hours.

The analysis can use the same trip categories reported in Table 2.1, inner, outgoing and ingoing, and is based on an in-depth investigation of the lists of requests.

The investigation is based on the following phases:

- **Initial pool generation**. Some nodes of the route generate several trips to fill one or more vehicles (same origin and destination with same request time). The minimum size of a pool is half of vehicle capacity; the maximum size is the vehicle capacity. These are the pools.
- **Final pool generation**. Starting from the initial pools generated in the previous phase, for each pool, the requests with same origin and destination but with a different time are investigated. The ride-sharing capability could result in a little changing of request time for people. The time tolerance for accepting this changing is a parameter that has to be set during the simulation. According to such procedure, people accepting the time slightly changing are inserted in the same initial pool (if not already full), thus generating the final pool; it could happen that
    - all requests of time changing can be considered as accepted, thus allowing the insertion of further users in the initial pools generated before and increasing vehicle occupancy rate;
    - for example, in municipalities where people commute daily outside by train, those people can be asked to change their request time from one train to the previous or the next. Usually in peak hour, the high frequency of trains allows to change train in little timing distances (maximum of 15 min).
- **New path generation**. The changing of request time and the insertion of new users on the same vehicle can result in different paths. Thanks to the geomapping of all nodes; it is possible to know which are the paths planned and if there are people that can be picked up during this travel before arriving at the destination. It could happen that
    - in order to include detour time to be spent for each intermediate stop, other than picking up and delivering people, it is necessary to estimate such parameter into the planning of route;
    - for example, if there are people with same destination but different origins and with different request times, they can be included into the same pool with consequent path change.
- **'Lonely' trip analysis**. All the trips that cannot be included in the pool generation phases need to be planned. For each one of them, it has to be checked if a new pool can be generated and/or if they can be inserted in existing pools with the techniques of train changing and picking up along the path.

The final output of this step is provided by the final pools generated for all the system users, ready to be inserted in the vehicles.

2.1.2.6 Fleet Dimensioning

The fleet dimensioning starts from the final pools established in the previous step and assigns each of them to a vehicle. For each vehicle, the following iterative procedure for the route planning is provided:

- It starts its first route from the origin of the first outgoing pool; therefore, such pool is assigned to this vehicle.
- It follows the planning route for the first pool, and when it fulfilled the pool requests, it becomes again available.
- The vehicle is at the destination position of the first pool; thus, it 'searches' users in the inner and ingoing pools:
  - If there is one with origin equal to the present vehicle position, it begins a second route, and the vehicle arrives to the destination of this second one. The pool is assigned to the vehicle and vice versa.
  - If there is not a possible combination with inner or ingoing pools for the return route, the vehicle starts empty, and the scheduling depends on travel time to reach the origin of a next available pool.
- After that, the vehicle is able to serve other pools, and it continues the iterative procedure until it serves all pools available.

If there are pools not assigned to a vehicle, a new vehicle will be required, and for each operating vehicle, a procedure like that previously described will start.

The number of vehicles requested for the fleet (and their capacity) is automatically defined when all pools have been assigned and represents the output of this step and the final output of the procedure (supply).

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CHAPTER 2.2

Determining ARTS Speed Profiles on the Basis of Infrastructures

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2.2.1 ARTS MAXIMUM ALLOWED SPEEDS: HOW TO ESTABLISH THEM?

The previous paper [1] described how to dimension an ARTS for the last-mile transport in terms of OD matrix, vehicle fleet, user pool per vehicle and paths to provide the service and represents the basis on which this paper has been built. Thus, the last phase of the dimensioning procedure [1], consisting in the route analysis in order to enable the automated vehicle operations, is the core of such paper.

The factor to be taken into account and established is the ARTS maximum allowable speed. To define the ARTS maximum allowable speed (and consequently the ARTS speed profiles), a methodology has been made, calculating the 'time to collision' between an ARTS vehicle and a pedestrian crossing the ARTS route (corridor) and adapting the ARTS speed in order to avoid the collision.

In the local public transport (LPT) services, each vehicle follows its proper path; such paths usually are made of and share sets of roads (e.g. in the city centres).

A corridor is defined as a road portion that includes at least one road arc (and it could include more than one arc belonging to different paths at the same time).

The methodology allows the calculation of the time to collision and the consequent infrastructure adaptations required and outcoming corridor capacity.

The speed profile inside the corridor is directly linked with the maximum allowable speed. It depends on the following factors:

- Other users' speed
- Distance between the vehicle and a user crossing its route (or an obstacle that obstruct lateral vision)
- Automated braking vehicle capabilities
- Internal vehicle configuration (sit places, stand and with or without safety belt), influencing directly the maximum deceleration in order to guarantee safety and comfort for passengers

A simultaneous localisation and mapping (SLAM) algorithm determines the automated vehicle trajectory in order to avoid obstacles (both static and dynamic); see Refs. [2,3]. Indeed, when there is a predetermined trajectory for the automated vehicle into the corridor, as in transport lane, it cannot dodge anything, but it changes only the speed.

The static objects are avoided with a designing procedure of vehicle trajectory, whereas for dynamic objects, the automated vehicle needs an intermediate analysis for the decision-making process on how to avoid collision with them.

In order to prevent any possible collision with the dynamic obstacles, the ARTS vehicle has to 'choose' the safest condition; it means that any object should be considered as crossing vertically the vehicle trajectory (worst condition).

After this introductory section, the next sections report the four different possible hazards on the ARTS lanes (Section 2.2.2), how to determine the maximum allowable speeds on an ARTS lane in the worst hazard configuration (Section 2.2.3) and the application of this methodology to the Trikala CityMobil2 site (Section 2.2.4).

2.2.2 POSSIBLE HAZARDS ON THE ARTS LANES

Four different hazard configurations have to be considered in order to have a complete framework of the possible intrusions into ARTS vehicle trajectory along its lane:

1. The pedestrians (or cyclists) are able to cross the ARTS lane, and there are no lateral obstacles close to the lane.
2. The pedestrians (or cyclists) are able to cross the ARTS lane, and even if there are lateral obstacles close to the lane, the vehicle is able to detect the pedestrians without lateral obstruction.
3. The pedestrians (or cyclists) are able to cross the ARTS lane, and there are lateral obstacles that partially obstruct lateral vision and cause a blind spot for ARTS, resulting in pedestrians (or cyclists) crossing suddenly the ARTS lane.
4. The pedestrians (or cyclists) are not able to cross the ARTS lane because of lateral obstacles that avoid their intrusion in the ARTS lane, and there are lateral obstacles that partially obstruct lateral vision and cause a blind spot for ARTS, resulting in pedestrians (or cyclists) not crossing the ARTS lane at all.

In order to explain the four hazards, a scheme representing the configuration of each one of them on the Oristano demonstration lane (picture of it reported in Fig. 2.1) is provided in Figs 2.2–2.4.

Fig. 2.1 Picture of Oristano ARTS lane.

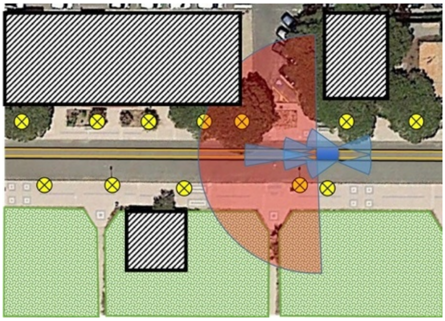

Fig. 2.2 ARTS lane, hazards nr. 1 and nr. 2 scheme.

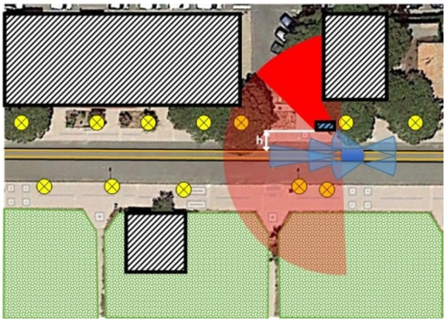

Fig. 2.3 ARTS lane, hazard nr. 3 scheme.

Fig. 2.4 ARTS lane, hazard nr. 4 scheme.

Table 2.2 Legend of symbols

Symbol	Description
	Area scanned from ultrasound sensor
	Buildings
	Objects (obstructing lateral vision)
	Objects (not obstructing lateral vision)
	Vehicle
	Area scanned from LIDAR sensor
	Blinding spot area
	Physical barrier

Table 2.2 shows the legend of the symbols reported in Figs 2.2–2.4.

Fig. 2.1 reports a picture of the ARTS lane in the section where the different possible hazards have been considered.

In Fig. 2.2, the scheme of the first two possible hazards is reported. The vehicle has a free vision on the surrounding environment. If someone crosses the lane, the vehicle will be able to detect it with sufficient time to decelerate comfortably. Some objects as lamppost and trees are in the detection area, but their size at road level allows the vehicle to detect someone behind them without obstruction.

Fig. 2.3 shows the most dangerous hazard (the third one), where one or more objects occlude vehicle lateral vision (in this case, it is a bench, as reported in Fig. 2.1). If there is someone in the blind spot (Portion of the area scanned from LIDAR sensor, between the buildings and the object obstructing lateral vision in Fig. 2.3), the vehicle would not be able to detect what is behind the obstacle. The distance 'h' allows calculating the time to collision (minimum distance from obstacle) and its maximum allowable speed as described in detail in Section 2.2.3.

Fig. 2.4 shows the fourth hazard. In order to maximise the speeds of vehicle, a barrier or a wall (marked with the box between the buildings and close to vehicle trajectory in the figure) avoids the intrusion even if it obstructs lateral vision. With this configuration, the maximum vehicle speed is directly linked with the regulation on the lane.

2.2.3 ARTS MAXIMUM ALLOWED SPEEDS FOR THE MOST DANGEROUS HAZARD CONFIGURATION

The previous section reported the four possible hazard configurations for the intrusion in an ARTS lane. The most dangerous is the third, where there is an obstacle close to vehicle trajectory that obstructs lateral vision behind it. In this section, the methodology to calculate the time to collision in such configuration and to adapt the maximum allowable speed to it is reported.

Any vehicle operating on such lane cannot see if there is someone (e.g. a pedestrian or a cyclist) going to cross the lane.

In order to prevent any possible collision with any user that could move behind these obstacles, the vehicle has to choose a safe condition to avoid collision; it means to consider that any user could cross vertically (worst condition) its lane.

In this case, the vehicle has to decelerate up to maximum allowable speed, and the methodology proposed aims to calculate it.

This methodology is made of two main steps, each one of them made of substeps:

- Time to collision and maximum allowable speed calculation
  - Other users' speed (pedestrians, cyclists and other vehicles) that interacts with potential corridor (ARTS lane) calculation
  - Distance between obstacles and vehicle calculation
  - Time-to-collision calculation
  - Maximum allowable speed calculation
- Corridor capacity evaluation
  - Mitigation action
  - Iterative procedure for all path and determining the whole ARTS network capacity

2.2.3.1 Time to Collision and Maximum Allowed ARTS Speed Calculation

2.2.3.1.1 Other Users Speed Calculation

Other users' speed calculation consists of a road inspection (or aerial imaging evaluation) with the aim to know which user category is across the corridor.

It also consists of maximum speed evaluation of these users; for example, if there is a cycle lane, the average speed is 13 km/h, and the speed limit reaches 30 km/h [4].

A bump or dedicated barrier could mitigate the maximum speed; this action has to do closeness to crossing with corridor to guarantee the action forcefulness.

For pedestrians, 1 m/s can be assumed as average speed.

2.2.3.1.2 Distance Between Obstacles and Vehicle Calculation

The calculation of the distance between obstacles and vehicle can be done with an experimental technique or a cartography analysis.

The experimental technique uses a vehicle equipped with some laser imaging detection and ranging (LIDAR) sensors that measures the distances

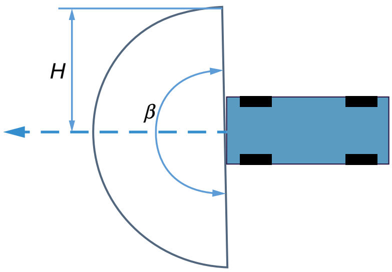

Fig. 2.5 Vehicle measuring with LIDAR sensors.

directly on field; it measures distances between physical objects and laser emitter. Commonly, sensors measure up to 30 m (H) from sensor emitter with an angular range (β) of 180 degrees (Fig. 2.5 and more information at Ref. [5]); usually, the sensors are in the front of the vehicle.

Otherwise, when the direct measure is not possible, it is sufficient that a detailed cartography or aerial imaging is measured in order to measure roads, sidewalk, buildings and all possible objects (such as trees, hedges, benches, walls and hurdles) near less than 30 m from the path.

2.2.3.1.3 Time to Collision Calculation

Fig. 2.6 shows the schematisation of time-to-collision problem. Each object is simplified as a point, and consequently, some tolerances are considered in the distances, usually half of maximum vehicle width or length.

The automated vehicle A moves along T_A trajectory with constant speed V_A.

Vehicle B (or pedestrian, cyclist, etc.) moves along T_B trajectory (perpendicular to T_A) with constant speed V_B, and it has distance d_A from the vehicle A trajectory.

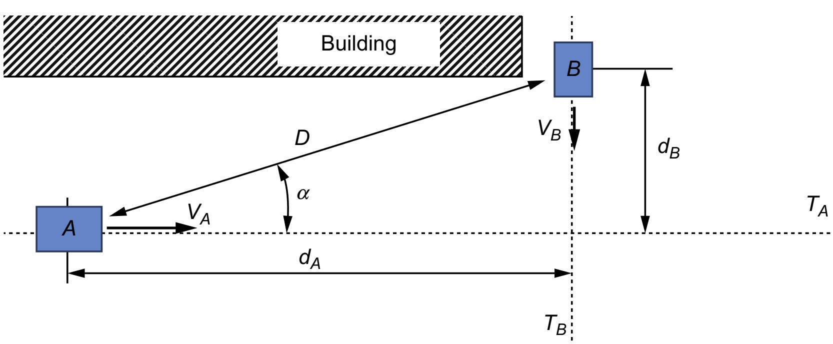

Fig. 2.6 Time-to-collision problem schematisation.

Such a scheme is valid as long as B would be able to reach first the intersection between the two trajectories T_A and T_B.

LIDAR sensors measure the direct distance D and the angle of detection α, and then, it identifies both d_A and d_B.

When A detects B, it needs a reaction time 't_R' to elaborate the data and activate suitable countermeasure (like emergency braking); during this time, it moves with uniform movement (see Eqs 2.1–2.3); then, it brakes with maximum constant deceleration until it stops (uniformly accelerated movement in Eqs 2.4, 2.5); the maximum braking distance to avoid collision is d_A.

Vehicle B moves with uniform movement (see Eqs 2.6–2.8).

The following equations represent what happens from time t_0, when A detects B, to time t_1 when B intercepts the trajectory of A.

Input data are the speeds V_A ($V_{A0} \neq 0$ and $V_{A1} = 0$) and V_B (constant), distance d_B, time t_R and acceleration a (or deceleration with negative sign).

The reaction time is usually set to 0.3 s [6]; it depends from the technology adopted and from the algorithms that manage automated vehicle. For a comparison, a driver has 1.37 s as average reaction time [7].

Maximum comfortable deceleration 'a' (with negative sign) of vehicle A depends on vehicle type and passenger situation inside of it.

For example, if passengers sit with face forward and they use a conventional safety belt, the maximum allowable braking deceleration is up to $5\,\text{m/s}^2$ [8]. Instead, a vehicle with standing passengers and no safety belts is allowed to have $1.2\,\text{m/s}^2$ maximum deceleration:

$$\text{Vehicle } A \quad \begin{cases} \text{Time } t_0 \div t_R \begin{cases} V_{A_R} = V_{A_0} & (2.1) \\ S_{A_R} = S_{A_0} + V_{A_0} \cdot (t_R - t_0) & (2.2) \\ d_A = S_{A_R} - S_{A_0} & (2.3) \end{cases} \\ \text{Time } t_R \div t_1 \begin{cases} V_{A_1} = V_{A_R} + a \cdot (t_1 - t_R) & (2.4) \\ S_{A_1} = S_{A_R} + V_{A_R} \cdot (t_1 - t_R) + \frac{1}{2} a \cdot (t_1 - t_R)^2 & (2.5) \end{cases} \end{cases}$$

$$\text{Vehicle } B \quad \text{Time } t_0 \div t_1 \begin{cases} V_{B_1} = V_{B_0} & (2.6) \\ S_{B_1} = S_{B_0} + V_{B_0} \cdot (t_1 - t_0) & (2.7) \\ d_B = S_{B_1} - S_{B_0} & (2.8) \end{cases}$$

The maximum distance d_A came from the previous equations. Moreover, from the point S_{A_R} where the vehicle A begins to decelerate, the speed profile is also determined to stop the vehicle. This condition happens when vehicle A detects someone as vehicle B.

If vehicle A does not detect someone, it has to decrease its speed in order to avoid collision if someone arrives to the crossing.

If someone suddenly appears, the vehicle has to brake. For this reason, the speed has a higher limit that depends on the speed of object B and its distance from the trajectory.

The time to collision of B has to be equal to stopping time of vehicle A.

2.2.3.1.4 Maximum Allowed Speed Calculation

The maximum allowable speed V_{A_0} is automatically determined with Eq. (2.9), and it is valid for any t_0. During the deceleration, 'a' is a negative value:

$$\left(t_1 - t_0\right) = \frac{d_B}{V_{B_0}} = t_R - \frac{V_{A_R}}{a} \Rightarrow V_{A_0} = V_{A_R} = a \cdot t_R - \frac{a \cdot d_B}{V_{B_0}} \tag{2.9}$$

When vehicle A is in a condition meaning that it will reach first the intersection of the trajectory with B, it could accelerate again.

This equation is valid only if the ratio between d_{B_0} and V_{B_0} is greater than t_R.

The braking distance is 'Δ', equal to the difference between S_{A_1} and S_{A_0} (see Eq. 2.10):

$$\begin{cases} \left(t_1 - t_R\right) = \left(-\dfrac{V_{A_R}}{a}\right) \\ \Delta = S_{A_1} - S_{A_0} = \left(S_{A_1} - S_{A_R}\right) + \left(S_{A_R} - S_{A_0}\right) = -\dfrac{1}{2} \cdot \dfrac{{V_{A_R}}^2}{a} + V_{A_R} \cdot t_R \end{cases} \tag{2.10}$$

The braking distance is useful to determine the distance from the detected obstacle where to satisfy the maximum allowable speed condition.

Theoretically, when automated vehicle passes the brake point, it could accelerate again because any user with speed up to the design speed arrives at intersection after the automated vehicle.

Indeed, for the tolerances adopted as vehicle dimensions, speed of user in the blind spot, comfort for passengers inside automated vehicle and so on, it is however safe to maintain the maximum allowable speed until the vehicle passes the obstacle, and it can light the blind spot with lateral vision.

For example, the hazard nr. 3 is shown in Fig. 2.3 of Section 2.2.4 (possible hazards on the ARTS lanes), with a bus ($1.2\,m/s^2$ of maximum deceleration 'a'); the t_r is equal to 0.3 s; the bench distance 'd_B' from vehicle side is equal to 2 m.

If behind the bench there is only pedestrian (with maximum speed of 1.5 m/s), the maximum allowable speed of vehicle when it detects the bench is 1.2 m/s (less than 5 km/h). The braking distance is 0.96 m.

A car with $4\,m/s^2$ of maximum deceleration aims to reach 4.1 m/s (less than 15 km/h) of maximum speed, with braking distance of 3.33 m.

The main difference between bus and car is the maximum allowable speed due to the allowed maximum deceleration; it means that car has a greater capacity and it needs to maintain this speed within the braking distance from obstacle.

2.2.3.2 Corridor Capacity Evaluation

A section-by-section calculation determined the maximum allowable speed for automated vehicle (see Eq. 2.9). Thereafter, it needs a filter operation to obtain the smoothest possible and comfortable speed profile.

The minimum distance between two sections for time-to-collision calculation depends on method chosen for measuring the distances; it is typically less than 1 m.

The more close they are, the more complex the calculations are, and it requires more time. It could be increased/reduced in order to fit the best performances of analysis; moreover, if the path is sufficiently clear from obstacle and if there are no obstacles (also if it is for a little part of the path), the section for this analysis could rise significantly, even more than 1 m.

Eq. (2.11) shows corridor capacity 'C_C' that depends on capacity 'V_C' and maximum frequency 'f'. Corridor capacity increases with vehicle speed (frequency inside of corridor rise) [9]:

$$C_C = V_C \cdot f \tag{2.11}$$

The time occurred to complete the path for a vehicle (t_{OCC}), with the speed profile just determined, represents the first step to determine the capacity of the lane.

Moreover, the frequency depends on the following variables:

- Corridor speed
- Vehicle length 'V_l'
- Braking strategy as brick-wall stop or vehicle maximum deceleration [9]

- Vehicle type or if available its maximum braking capability
- Passengers' condition inside the vehicle (stand, sit and with or without safety belt)

As a general remark, the frequency follows Eq. (2.12). The 'n_v' is the number of vehicles available for the lane:

$$f = \frac{1}{t_{OCC}} \cdot n_V \tag{2.12}$$

The choice of vehicle type changes the corridor capacity. Some mitigation solutions could reduce speed of other users and allow increasing the speed of automated vehicles.

2.2.3.2.1 Mitigation Actions

This subsection aims to explain some possible interventions to improve safety of corridors. It could be possible by two different procedures:

I. Speed reduction of other vehicles/users that can cross automated vehicle route, as the barrier shown in Fig. 2.6 of the previous section.

II. Speed reduction of automated vehicle together with alert signal provided by infrastructure sensors. The sensors light the blind spots that automated vehicle cannot see and provide to it a signal of the other vehicles/users' presence; this solution allows reducing the speed of automated vehicle before arriving at the crossing only when someone is going to cross there.

Such actions regard all automated vehicle path, including sidewalks, benches, trees and other nonconventional obstacles (i.e. flower box, fountain or sculptures), and the crossing with other roads (these last ones are discussed in detail in Ref. [10]).

Table 2.3 shows the impacts of both types of solutions, in a scale from 1 to 3 (1 means low/poor, and 3 means high/good). All value represents the average solution for both type, but they depend on the mitigation action achieved.

Table 2.3 demonstrates that Solution I is preferable, but sometimes, the infrastructure intervention for mitigating the speed of other vehicle could be too expensive.

Table 2.3 Mitigation action impacts

Solution	Corridor capacity	Safety	Reliability	Cost
I	3	3	3	2
II	2	2	2	1

Some of the possible mitigation actions are as follows:

- A physical barrier to slow down users (pedestrian and cyclist) or to avoid the passing of them
- A physical untraversable barrier to avoid pedestrian crossing outside of zebra crossing
- Bump above-ground or underground (road level)
- Crossing lights or smart lights
- Speed cameras

At the moment, there are a few prototypes of electronic devices (such as electric bump and smart crossing lights) that produce the desired mitigation only for high-speed users without slowing down the other ones.

2.2.3.2.2 Iterative Procedure for All Paths Determining the Whole ARTS Network Capacity

An iterative procedure evaluates the time to collision for all section of path, builds the speed profile and calculates the corridor capacity for some types of vehicles (with different braking capabilities).

Moreover, it could assess several different mitigation actions in those crucial points with low allowable speed and calculates the variation of corridor capacity for them.

It could happen that a large vehicle (such as a bus with 30-passenger capacity) produces less capacity than a little vehicle (such as a car with 4-passenger capacity, with seated passengers and seatbelt).

It happens because for the bus a lower maximum deceleration is required, and it needs to decrease its speed more than the car. It is the same issue for the acceleration phase after passing the crucial point.

Moreover, bus has more stops to pick up and deliver passengers from vehicle; more passengers means more stops and more time-wasting for accelerating and decelerating vehicle comfortably.

The whole ARTS network capacity is equal to the minimum corridor capacity from those of all corridors of the network.

This is why it is important to use suitable mitigation actions in order to increase the capacity of those lanes with dangerous situations. Otherwise, it would be necessary to adopt more vehicles to obtain the same passenger capacity, resulting in further costs and possible congestion on the route.

2.2.4 THE METHODOLOGY APPLICATION TO THE TRIKALA SITE IN GREECE

One of the three 'CityMobil2' large demonstrations was in Trikala; the ARTS lane followed the route in Fig. 2.7.

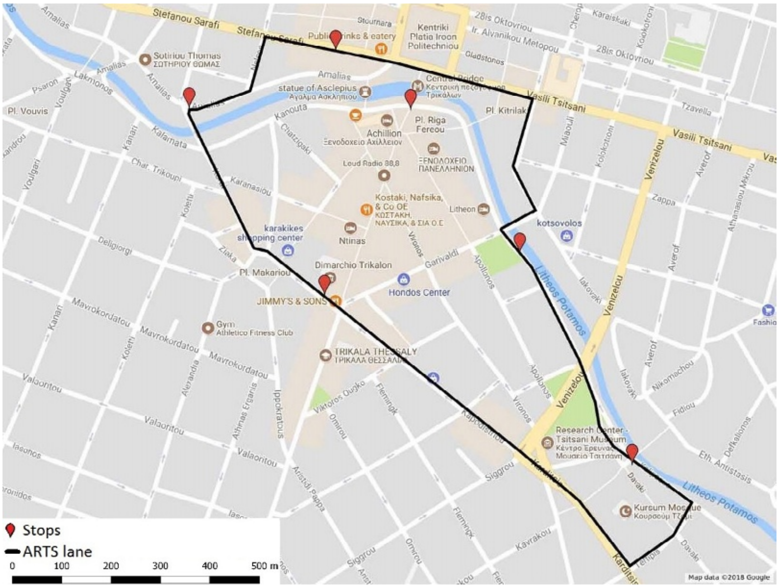

Fig. 2.7 Trikala site and ARTS route.

In this section, several pictures regarding the demo are reported, in order to show a practical application of the methodology reported here. For what concerns the urban integration of the ARTS in Trikala and the management of the intersections the vehicles crossed, the principles adopted can be found in detail in Refs. [10,11], respectively, and are not extensively reported in this section.

The lane was not segregated.

The LIDAR measured distances from vehicle to the surrounding environment, and for a significant analysis, this scan had to be repeated several times.

After the scan procedure, all data needed a filtering phase in order to keep only data regarding buildings and static objects and removing the dynamic ones (like people, cars and so on).

Figs 2.8 and 2.9 (with a zoomed view) show data elaboration for Trikala site. The external dots show static objects and obstacles; the internal continuous dots show the trajectory of automated vehicle, and the dots highlited inside such trajectory represent where the obstacles are too close to the vehicle (less than 1 m close to the vehicle width).

As reported in Fig. 2.9, LIDAR sensors were able to detect all objects as barriers and sidewalks. When passing at crossroads, nothing was detected, because the distance from objects is higher than 30 m.

This analysis went on with the calculation of time to collision and maximum allowable speed for each section (each dot) of vehicle trajectory.

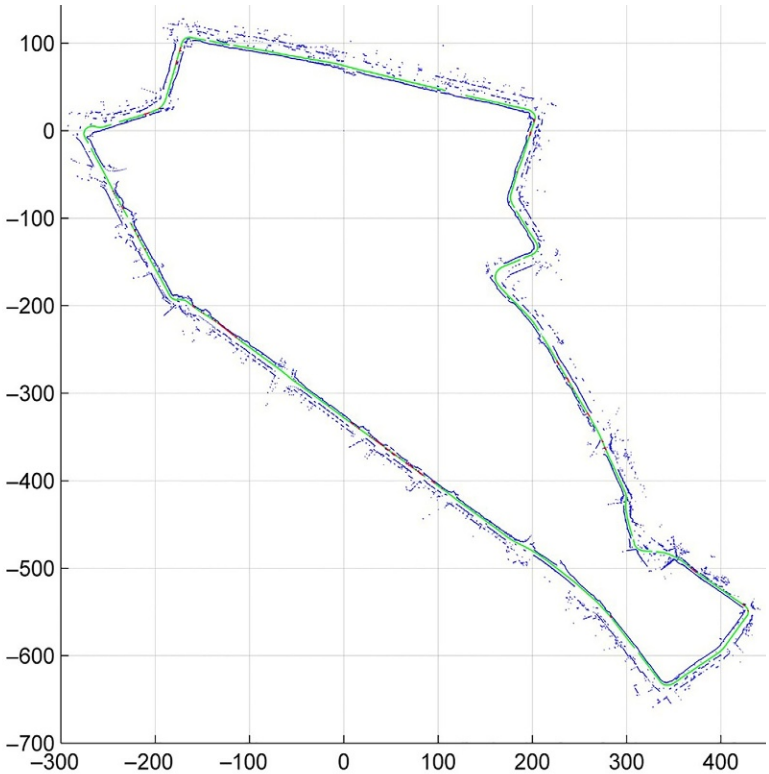

Fig. 2.8 Trikala scan elaboration and data-filtering phase.

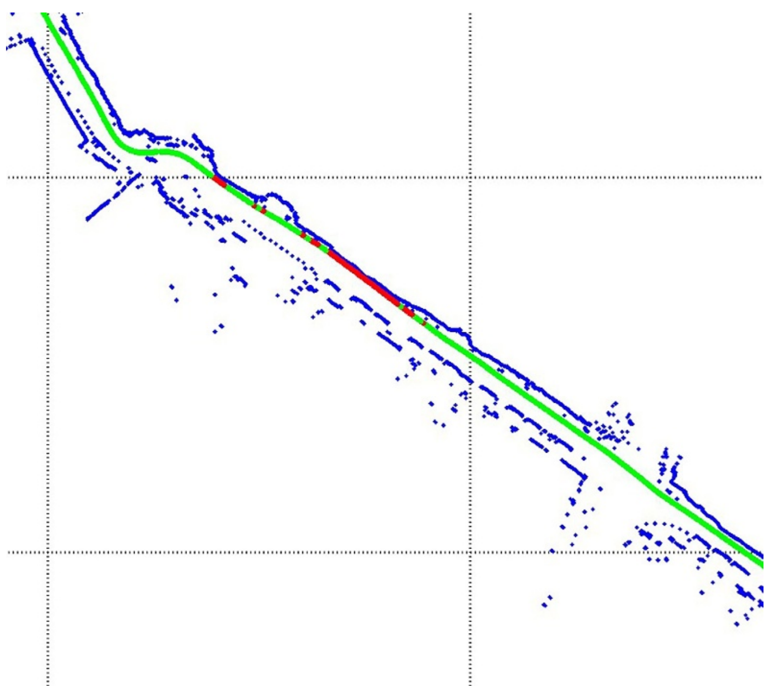

Fig. 2.9 A zoom of Fig. 2.8.

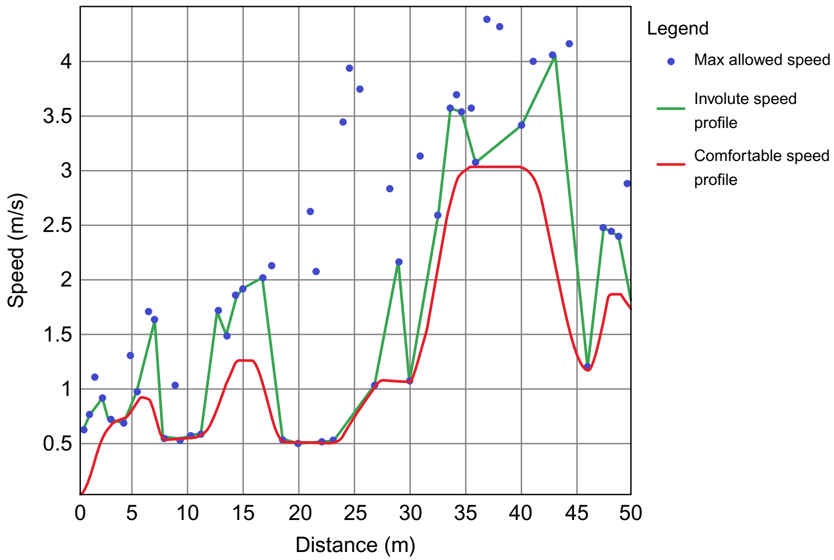

Fig. 2.10 Speed profile elaboration.

Fig. 2.9 shows with the external dots the maximum allowable speed for each point of the trajectory (with a distance in metre of a curvilinear abscissa), and then, a first filtering phase determines the internal line that vehicle is able to do.

Thereafter, a smoothing phase for the speed profile gave the right driving comfort into the corridor (or as in Trikala site for full path); this phase identifies the light line, starting from zero and located on the lower part in Fig. 2.10.

The comfortable speed profile allows calculating the corridor capacity.

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CHAPTER 2.3

Integrating ARTS in Existing Urban Infrastructures: The General Principles

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2.3.1 INTRODUCTION

Automated vehicles, whether autonomous or part of an ARTS, do need careful consideration on how to use the 'built environment'.

Motorways are simplified environments (no pedestrians, clear lane separation, merging-diverging intersections, clear fields of view for sensors, segregated carriageways, …), and yet, they are environments in which accident risk will remain high due to high speed and reduced distances that make any mistake potentially fatal. Motorways will become safer thanks to automated vehicles, which will reduce the human errors, but at the same time, 'technology errors' (whether they are failures or misjudgements of a technology that was thought to think) will have huge consequences and no obvious fail-safe option. Furthermore, as long as manually driven vehicles will be allowed to mix with automated ones, preventing other drivers' mistakes might prove impossible reducing dramatically the positive safety effects. Car makers have concentrated first on motorways because this is where driver-assist functions will give their best.

On the other hand, urban environments are much more complex (corners, mix of different road users with different behaviours, different speeds and different resilience to crashes, unconventional road geometries, uneven pavements …), but with speed considerably lower, easier automation solutions are possible and have already proven effective. Integrating an automated vehicle in any urban environment, however, might need a rethinking of the urban environment. Left-side turning on a multiple-lane road, with traffic light and even worse without it, is as much of a challenge for automated vehicles as it is for manual drivers. In designing the vehicle behaviour, it is possible to make it aggressive, forcing its way even with small gaps, with the risk of causing even more accidents, or making it safe, with the risk of drastically diminishing the infrastructure performance. The win-win solution exists only if automated vehicles can rely on infrastructures to help them, either with safer design or with communicating road-side sensors or both.

This paper reports examples of ARTS integration in existing urban infrastructures, reporting the general principles to insert an ARTS correctly. Such insertion starts from the dimensioning of the ARTS reported in Ref. [1] and changes on the basis of the ARTS speed profile adopted, as reported in Ref. [2].

Therefore, the urban integration can be considered as the third step of the ARTS stepping out on the stage of the urban mobility, where the first step is represented by its dimensioning [1] and the second step by its speed profile definition [2]. Once integrated in the urban infrastructures and managed the intersections as detailed in Ref. [3], the ARTS is ready to be part of the urban mobility.

2.3.2 SELECTION OF THE NETWORK PORTION TO INTEGRATE ARTS: GENERAL PRINCIPLES

2.3.2.1 Roads Classification Adopted

The following classification, based on the TRB Highway Capacity Manual (HCM) [4], can be used at a European level. The glossary of the TRB HCM provides very detailed but sometimes overlapping road definitions, based on the technical characteristics of the road. Since this classification is mainly oriented to analysis and evaluation of the level of service (for vehicle traffic) in transportation facilities, pedestrians and bicycles are only taken into account as a type of traffic flow. The following glossary provides the definitions used in the HCM:

- Freeway—a multilane, divided highway with a minimum of two lanes for the exclusive use of traffic in each direction and full control of access without traffic interruption
- Highway—a roadway with at least two lanes, one lane for each direction of flow, for the exclusive use of traffic in each direction, with partial control of access, but that may have periodic interruptions to flow at signalised intersections
- Arterial road—a signalised street that primarily serves through traffic and that secondarily provides access to abutting properties
- Urban street—a street with relatively high density of driveway access located in an urban area and with traffic signals
- Collector street—a surface street providing land access and traffic circulation within residential, commercial and industrial areas
- Walkway—a facility provided for pedestrian movement and segregated from vehicular traffic by a curb or provided for on a separate right of way

It constitutes a general road classification, starting from which different CityMobil2 scenarios were identified and designed for road categories C, D, E and F.

2.3.2.2 ARTS Lane Classification and Potential Scenarios

2.3.2.2.1 ARTS Lane Classification

When an automated vehicle starts communicating, relying on known infrastructures and communication, it ceases to be autonomous and becomes part of an ARTS. ARTS vehicles can share the road with any other road users; the rules of such sharing need some definition. The CityMobil2 project defined in 2013 the following three types of lanes [5]:

- **Segregated**—these are protected lanes in which barriers seclude the lane from the rest of the users; other users can still be allowed but barriers force them to respect a predictable and simplified behaviour. The CityMobil2 project recommended segregated lane for any high-speed operation (above 40 km/h). If manual vehicles are not allowed on such lanes as the space consumption is very high, it is recommended that the lanes are used for high-speed high-capacity operations through platooning so to guarantee a throughput of more than 3000 vehicles per lane per hour against 2000 of manual driving.
- **Dedicated**—when the lane used by ARTS vehicle is clearly identified with signs and road markings but it's use is not forbidden to other road users (pedestrians and cyclists in some cases and other motorised vehicles) who follow a few special rules (not to overtake, not to stop and do not follow the vehicle ARTS at distances less than the safety distance). Such lanes are very conventional, just minor modifications, and a certification procedure to guarantee safety is needed.
- **Share access**—in this last category is the ARTS vehicle that enters a normal lane without any special precautions. In CityMobil2 project, such lanes have proven to be very ineffective to use; an automated vehicle always needs to check that the infrastructure is safe; if not, it needs to slow down for any potential threats and risks to degrade the road infrastructure performance.

The matching between ARTS lanes of all types and lanes for manual vehicles is always possible provided that certain measures to ensure the safety of the matching are met.

2.3.2.2.2 ARTS Potential Scenarios

Three potential scenarios are presented in this section:

- ARTS fully segregated lane
- ARTS partly segregated lane
- ARTS fully dedicated lane

Since all the following scenarios define that the ARTS vehicles drive on a dedicated or segregated lane, ARTS vehicles always have the priority over the other motorised traffic.

This priority rule changes only at crossings, which shall always be controlled either by barriers, by horizontal and vertical markings or by traffic lights, as reported in Chapter 2.4.

In all cases, the automated vehicles can potentially drive in an ARTS dedicated or segregated lane at a maximum speed defined by the following road classes:

- C—arterial road: speed limit 55–80 km/h and maximum ARTS speed 55 km/h
- D—urban street: speed limit 40–55 km/h and maximum ARTS speed 40 km/h
- E—collector street: speed limit 15–40 km/h and maximum ARTS speed 20 km/h

These speed-limit ranges are based on the legal regulations found applicable in the CityMobil2 cities [5].

2.3.2.2.3 ARTS Fully Segregated Lane

ARTS fully segregated lane scenario is applicable to the following road classes:

- Arterial road
- Urban street

Maximum speed of the ARTS vehicle in the ARTS lane and in the crossings is defined according to the scheme previously reported according to road category.

The segregated lane is longitudinally protected on both sides with continuous physical barriers at least 1.2 m high. Its width is at least 0.5 m larger than the vehicle width at each side. To be fully segregated and to prevent the presence of any obstacle on the ARTS lane, the stations are equipped with station doors that shall be designed in order to guarantee that a person cannot access the ARTS lane while the doors are closed. The doors open exclusively when the vehicle is docked. Doors for stations are part of the system that manufacturers must provide.

No road users outside of the ARTS vehicle are supposed to be present on the ARTS lane, not even bicycles or pedestrians. Despite the segregation, trespassers can surpass the barriers. In order to guarantee that eventual trespassers will not be hurt, the ARTS shall be able to detect pedestrians, present in the ARTS lane in front of the ARTS vehicle, in which case the operator must be informed. If the pedestrian is at his stopping distance, then the vehicle must make an emergency braking. The ARTS lane must also be equipped with escape ways.

The following segregation elements can be found in the environment (see detailed images in Section 2.3.4):

- Continuous barriers: balustrade and pedestrian protection barrier (for pedestrians)
- Carriageway divider (for motor vehicles)

The crossings with motor vehicles or with pedestrian flows are regulated by a combination of traffic lights and removable barriers, which prevent road users from entering the ARTS lane, by closing when the transversal movement phase is completed. Crossings for driveways operate upon the request of the concerned motor vehicle drivers. The width of the ARTS lane does not allow an overtaking manoeuvre.

Limit case: If a person crosses the barriers, violating the safety perimeter imposed by these elements, and is located at a distance to the ARTS that is smaller than the emergency braking distance, then the potential injury (or accident) cannot be avoided. The vehicle can just brake at an emergency braking limit situation in order to minimise damage.

2.3.2.2.4 ARTS Partly Segregated Lane

ARTS partly segregated lane is applicable to the following road classes:

- Urban street
- Collector street

Maximum speed of the ARTS vehicle in the ARTS lane and in the crossings is defined according to the scheme previously reported according to road category.

An ARTS partly segregated lane differs from an ARTS fully segregated lane in the following aspects:

- The stations are not equipped with doors.
- The crossings with motor vehicles and/or with pedestrian flows are regulated only by traffic lights.

No road users are supposed to be present on the ARTS lane, not even bicycles or pedestrians.

Despite the segregation, trespasser or unaware pedestrians and motor vehicle drivers can enter the ARTS lane in the crossings, and unaware ARTS users can enter the ARTS lane in the stations. In addition, even if not authorised, cyclists may use the ARTS lane as bike path and can approach the ARTS vehicle from the front and from the back, possibly try to overtake the ARTS vehicle or be approached by the ARTS vehicle from behind.

Besides all the necessary horizontal and vertical markings, in order to guarantee the ARTS integrity, and the ARTS and road users' safety, the

system shall detect any road user that enters the ARTS lane through the crossings or the stations, in which case the operator shall be informed and emergency procedures to avoid hazards (defined before opening the ARTS to the public) shall be activated.

It implies that the infrastructure must be equipped with communicating supervision sensors. If the operator is informed later than the trespasser road user encounters the ARTS vehicle, the vehicle detects the obstacle, stops if needed to avoid hazard and informs the operator. The infrastructure equipment that allows detecting unidentified vehicles is part of the system that manufacturers must provide.

When the vehicle is not docked in the station, the system prevents users from entering the ARTS lane through the station with visual and acoustic messages in local language and in English as soon as they approach the edge of the station.

Limit case: First limitation case is the same as for fully segregated scenario.

2.3.2.2.5 ARTS Fully Dedicated Lane

ARTS fully dedicated lane is applicable to the following road classes:

- Urban street
- Collector street

Maximum speed of the ARTS vehicle in the ARTS lane and in the crossings is defined according to the scheme previously reported according to road category.

The dedicated lane can be adjacent to a vehicle lane or to a bike lane on one side and to a walkway on the other side. Longitudinal raised segregation elements starting from lane delimiter prevent motor vehicles from entering/using the ARTS lane, but special vehicles, such as emergency vehicles, can possibly enter the ARTS lane. In case an emergency vehicle needs entering/using the ARTS lane, the operator will be informed and free the ARTS lane (e.g. prevent the vehicles from stopping in any station in the route planned by the emergency vehicle). The stations are not protected with station doors.

The following segregation elements can be found in the environment (elements that can hide a potential obstacle are indicated with a (*) sign):

- Differentiated lane paving
- Lane delimiter
- Surmountable curb
- Walkways
- Traffic median

- Discontinuous urban furniture: flower box, bollards, delimiter, etc. *
- Continuous soft barriers: vegetation *

It is not advisable to use elements signalised in the list above indicated with a (*) sign, because they generate occlusion areas that are difficult to monitor from the ARTS vehicle.

They segregate the ARTS lane from motorised vehicles, but not from pedestrian and bicycle crossing. However, when these elements cannot be removed, the ARTS shall limit the vehicle's speed when approaching these elements.

All crossings with motorised vehicles are regulated by traffic lights. Motorised vehicles are supposed to cross the ARTS lane only in specific locations, provided for this purpose. Depending on the ARTS vehicles' posted speed, crossings for driveways are protected with traffic lights, and ARTS lane crossing by a motorised vehicle shall only occur if the ARTS is free, on the crossing trajectory. Although it is supposed that drivers respect the national highway code and do not enter in a dedicated lane unless they are allowed by traffic regulations, trespassers or unaware drivers (e.g. tourists) can be present and enter the ARTS lane at the crossings. Besides all the necessary horizontal and vertical markings, in order to guarantee the ARTS integrity and the ARTS users' safety, the system shall be capable of detecting unauthorised motorised vehicles (different from ARTS) that enter the ARTS lane, in which case the operator shall be informed and emergency procedures to remove hazards (defined before opening the ARTS to the public) shall be activated. The infrastructure equipment that allows detecting unauthorised motorised vehicles that enter the ARTS lane is part of the system that manufacturers must provide.

Pedestrians (in particular children) and cyclists can cross the ARTS lane unexpectedly at any moment, from both sides of the lane, especially in the narrowest streets. That is the reason why all the potential obstacles must be tracked, in order to calculate a collision risk by regarding the ARTS vehicle planned path and the obstacle predicted trajectory. The collision risk must be assessed in order to adapt the speed, warn incautious pedestrians and/or cyclists or make an emergency braking. The collision risk assessment shall take into account large objects in the environment, located near the ARTS lane, which can hide road users that might become potential obstacles. In addition, even if not authorised, cyclists may use the ARTS lane as bike path and can approach the ARTS vehicle from the front and from the back, try to overtake the ARTS vehicle or be approached by the ARTS vehicle from behind.

All pedestrian crossings are controlled with traffic lights.

Elderly and sensory-impaired persons are present and can be unaware of the ARTS vehicle or react slowly to it.

The ARTS lane width does not allow an overtaking manoeuvre.

Limit case: Obstacles that suddenly plough laterally on the ARTS vehicle will be difficult to anticipate.

2.3.3 EXAMPLES OF INTEGRATION ON ARTERIAL ROADS, URBAN STREETS, COLLECTOR STREETS

In this section, pictures of examples of urban integration are reported.

It is made of four subsections, the first three dedicated to the applications of the scenarios reported in Section 2.3.2.2.2 to arterial roads, urban streets and collector streets, respectively, and the fourth reported real urban integration application for conventional vehicles.

2.3.3.1 Arterial Roads

Concerning the arterial roads, two examples of ARTS lanes and their integration are reported.

The first one, shown in Fig. 2.11, reports an ARTS lane for an arterial road with three lanes per direction. The ARTS lane has to be segregated, and it replaces one of the lanes for conventional vehicles, placed on the side of the three main lanes and divided by another segregated lane (e.g. for bikes). In all the lanes, there is a pedestrian crossing. The reason for the ARTS segregation is that sharing the road at high speed (more than 70 km/h) can never guarantee a sufficient safety for ARTS vehicles. Any manually driven vehicle, either for losing control or for any other reason, can end up invading the ARTS lane and colliding with a vehicle.

The second example of Fig. 2.12 is different from the previous mainly for the position of the ARTS lane (which has to be again segregated), between three main vehicle lanes and one of the lanes on the side, which is not removed because there are no other dedicated lanes. As for the previous example, in all the lanes, there is a pedestrian crossing.

2.3.3.2 Urban Streets

The two examples concerning urban streets, reported in Figs 2.13 and 2.14, respectively, are both reporting an ARTS lane that replaces one of the conventional vehicle lanes. In the example of Fig. 2.13, there is one lane per direction; thus, the ARTS lane becomes the only lane in one of the two directions of the street.

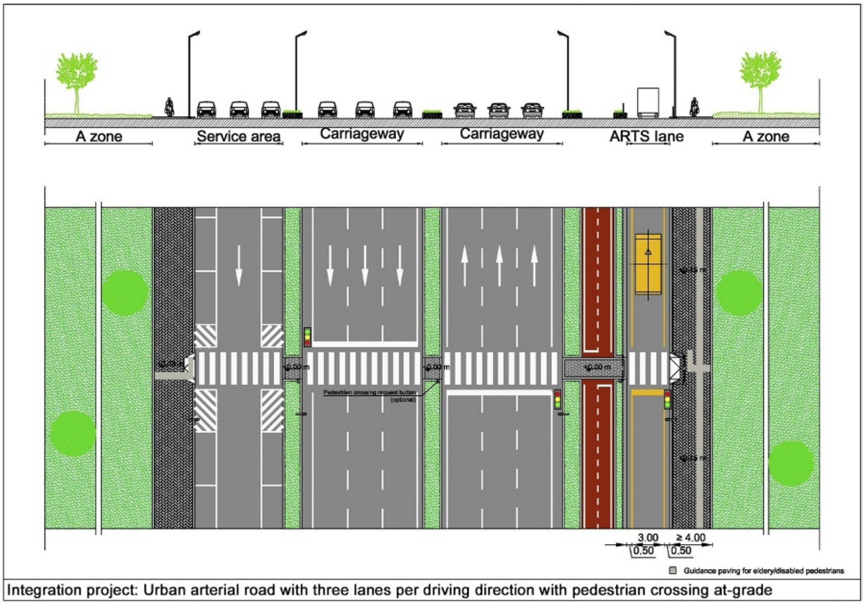


Fig. 2.11 Example 1 of integration of a segregated lane in an arterial road (TRB HCM class C).

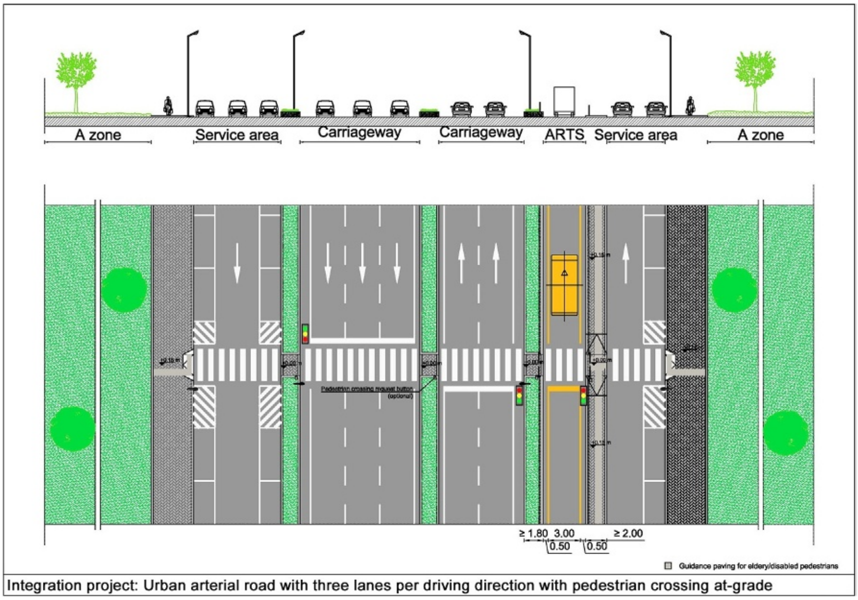


Fig. 2.12 Example 2 of integration of a segregated lane in an arterial road (TRB HCM class C).

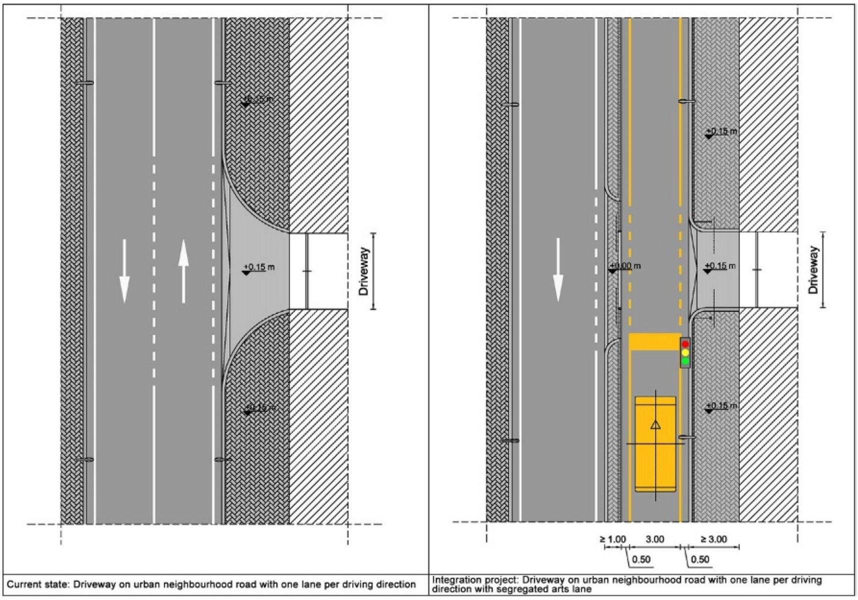


Fig. 2.13 Example of integration of a lane in an urban street with one lane per driving direction (TRB HCM class D).

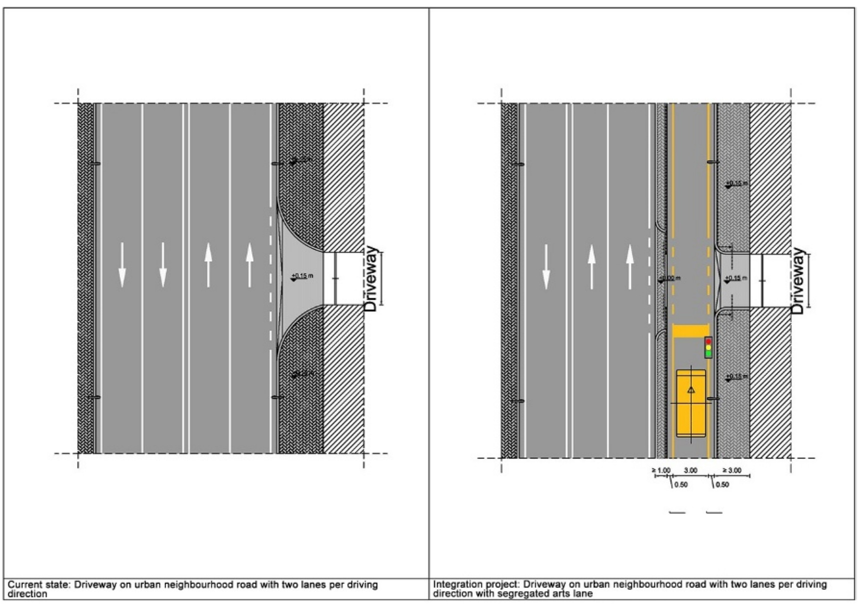


Fig. 2.14 Example of integration of a lane in an urban street with two lanes per driving direction (TRB HCM class D).

In Fig. 2.14, there are two lanes per direction, and the ARTS lane replacing one of them does not become the only lane in one of the two directions. However, the position of the conventional lanes is changed after the insertion of the ARTS lane, in order to avoid the insertion of conventional vehicles in it.

2.3.3.3 Collector Streets

The examples of ARTS lane insertion on collector streets reported in Figs 2.15 and 2.16 differ only for the direction of the conventional vehicles allowed after the ARTS lane insertion.

In both of them, one of the previously conventional vehicle lanes is replaced by the ARTS lane, and no parking is allowed after that, but in Fig. 2.15, conventional vehicles and ARTS go in two opposite directions, thus not allowing the possibility of conventional vehicles crossing ARTS lane, whereas in Fig. 2.16, the direction is the same for ARTS and conventional vehicles, and they can cross and use the ARTS lane if allowed in the design phase. The main thing to notice is the removal of road-side parking. This is due to the visual obstruction that parked cars make on the sensors of the automated vehicle (or to the eyes of the human driver for what it

Fig. 2.15 Example 1 of integration of a lane in a collector street with one lane per driving direction (TRB HCM class E).

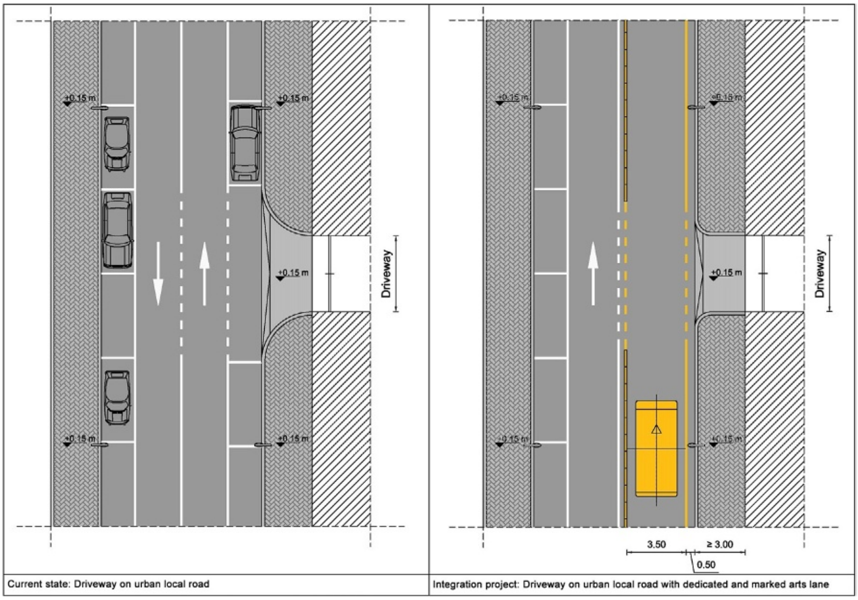


Fig. 2.16 Example 2 of integration of a lane in an urban street with one lane per driving direction (TRB HCM class E).

matters). For the automated vehicle to ride nearby, such obstructions mean being blind to anything (e.g. a kid), which could be hiding between parked cars and run suddenly in the middle of the street. The same risk arises with manually driven vehicles, but while killing a kid is such a rare event (nearly one happening every billion kilometres driven) that a driver can decide to sustain the risk, an automated vehicle cannot take such risk, and in case parked vehicles are not removed, the vehicle needs to slow down almost to pedestrian speed.

The maximum speed the vehicle is allowed to keep will depend on the visibility on the sidewalk. Time to collision (which depends on the vehicle and the other user speed and on the distance) needs to allow breaking with a deceleration that is sustainable for the vehicle occupants (lower if standing passengers are allowed).

Figs 2.15 and 2.16 were drafted by the CityMobil2 consortium at the beginning of the project as a technical specification and do not reflect the learning done during the project. Two key project findings would be reflected today in the same example in Figs 2.15 and 2.16.

The first is that the lanes in Figs 2.15 and 2.16 are uselessly widened. ARTS vehicles, respecting very precisely their designed trajectories, do not

need large lanes, and the larger the lane, the more other road users (such as fast cyclist or motorcyclists) can be tempted to overtake, which would induce a braking in the ARTS vehicles.

The second is that while removing parking from the ARTS lane side is necessary, removing it from the other side is not necessary because the width of the lane is a sufficient space to allow sensor visibility. Therefore (in light of keeping at least at first the same number of parking slots), the orientation of the other lane parking can be changed, and the width of the two lanes is kept as before.

2.3.4 EXAMPLES OF REAL URBAN INTEGRATION FROM JAPAN AND HOLLAND

This section reports four examples of real applications of the urban integration of dedicated or segregated lanes in existing streets.

Figs 2.17 and 2.18 show two examples of urban integration in Holland. In Fig. 2.17, the dedicated lanes are separated from the conventional lanes by a sidewalk, not allowing conventional vehicles to cross them. In Fig. 2.18, the lane on the left of the picture is separated by a hedge and cannot be crossed by vehicles, whereas the lane on the right can be crossed.

The example in Figs 2.17 and 2.18, pictures taken on a street in Delft in the area of the Technical University of Delft, is a second example of a road design made to improve safety for existing road vehicles that can be easily turned into a certified infrastructure for ARTS. There, the median is not enlarged as in the Japanese example, but it is elevated and difficult to surmount. This will prevent overtaking and frontal crashes. In the road sections exemplified by Figs 2.17 and 2.18, lanes could be certified for ARTS use in both directions. In fact, another important step towards safety is taken there; the cycle path on the left-hand side of the picture is 'softly' separated from the vehicle lane by a grass area. Any cyclist falling would not do so in the

Fig. 2.17 Example 1 of integration on Dutch streets.

Fig. 2.18 Example 2 of integration on Dutch streets.

middle of the street risking being run over by a motor vehicle but would do so on the grass. Furthermore, a cyclist deciding to invade the road would first need to cross the grass allowing the road vehicle sensors to detect misbehaviour and prevent accidents.

Figs 2.19 and 2.20 are pictures taken on a mountain route in Japan, the route linking Hakone to Odawara. It represents the perfect example of a road design

Fig. 2.19 Example 1 of integration on Japanese streets.

Fig. 2.20 Example 2 of integration on Japanese streets.

made to improve safety for existing road vehicles. As curves are tight to allow a higher speed while preserving safety, the median is 'enlarged' creating a buffer area not to be invaded by any car. Vehicles driving in one direction can detect misbehaviour from vehicles coming from the opposite direction and slow down to prevent crashes. A similar road design would allow ARTS to prevent most frontal collisions it would not however prevent from unwanted overtaking.

All such examples have been reported to show how the approach chosen for the ARTS lanes is based on real existing applications, to which the requirements needed to allow fully automated vehicles to circulate on them are applied.

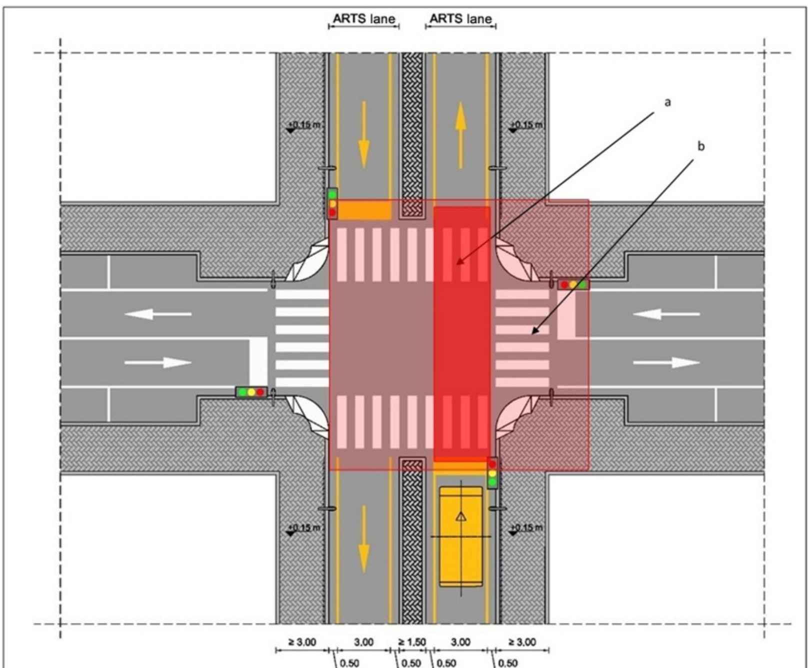
2.3.5 GENERAL APPROACH FOR THE INTERSECTIONS

The intersections between ARTS and conventional vehicles require safety procedures to manage them. Such procedures and requirements of any specifications change in case the intersections are signalised or not. The next

paper of part I of the book will describe in detail the safety maximisation for the signalised and nonsignalised intersections [3].

This section represents a brief description of the general approach for the intersections with the integration of an ARTS and is mainly based on the examples of intersection reported in Figs 2.21 and 2.22.

In Fig. 2.21, the intersection is managed by a traffic light that communicates with the ARTS vehicles, not only to inform them of the colours but also to receive a feedback on the vehicle position and whether they have cleared the intersection. The ARTS can cross (low speed) also nonsignalised intersections, but some measures must be taken to ensure that other vehicles also reduce the speed; it is recommended to insert the appropriate speed bumps on the manual vehicle lane; this is feasible only for roads with low traffic. The traffic light alone is not enough to guarantee safety. As shown in



Integration project: At-grade intersection between two urban local roads with segregated arts lane

Fig. 2.21 Example of integration of a cross between a neighbourhood urban streets (TRB HCM class D) with ARTS dedicated lanes and a second for manual car.

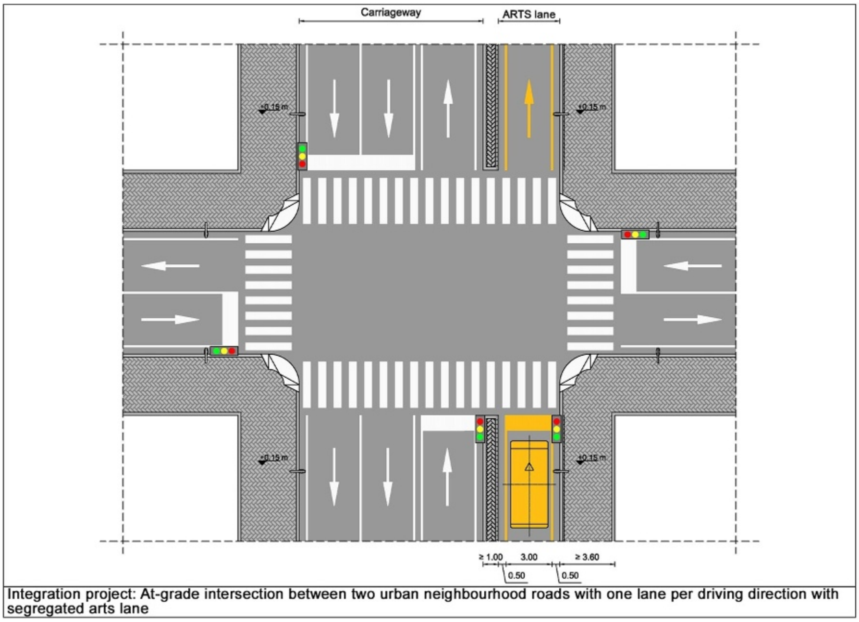


Fig. 2.22 Example of integration of a cross between a city street (TRB HCM classes D and E) with one lane dedicated ARTS and a second for manual car.

the figure, there are two areas that the sensors of the vehicle must be able to monitor. The first area (a) is one in which the presence of any obstacle activates an emergency braking; the second (b), of variable length according to the ARTS vehicle speed and variable amplitude depending of other road users' speed, is the one that induces slowdowns. If the speed of an incoming vehicle that can potentially 'jump the red' is 70 km/h (20 m/s) and the vehicle ARTS free the intersection in 10 s, the ARTS sensor should control at least 200 m of road. On the other hand, a vehicle 200 m away is not necessarily a threat because with a deceleration of 5 m/s^2, the vehicle may stop at 40 m. It is therefore recommended that the verification of the correct behaviour of manual vehicles is left at opportune sensors on the infrastructure.

The last detail to notice in the figure is the presence of a separator flows between the two-lane ARTS before and after the intersection to ensure that a vehicle in the emergency area (indicated with a in the figure) does not invade the opposite lane forcing the vehicle to frequent emergency braking (if a vehicle sensor suit sees another vehicle in its emergency area, the vehicle is forced to brake).

In analogy with Fig. 2.21, Fig. 2.22 presents another type of intersection between the upper-class roads. It is important to notice here that the median is between the ARTS lane and the one in the same direction to ensure that the other lanes do not invade the ARTS and create the buffer required for the sensors.

These examples are not meant to be exhaustive; they serve uniquely to understand the possible integration measures. In fact, every road section can have many different designs that are suitable, and they can all be accepted provided they are the result of the application of the procedure for risk assessment and mitigation described in the next paper of the book [3].

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CHAPTER 2.4

Integrating ARTS on Signalised and Nonsignalised Intersections for Safety Maximisation and Comparison With Conventional Car Safety Assessment

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2.4.1 INTRODUCTION

Intersections are locations where two or more roads join or cross one another. The crossing and turning manoeuvres that occur at intersections create opportunities for vehicle-vehicle, vehicle-pedestrian and vehicle-bicycle conflicts, which may result in traffic accidents.

Signalised and nonsignalised intersections have specific characteristics entailing different traffic accident patterns and road safety conditions. Nonsignalised intersections are of particular concern because they normally are the majority in urban areas and because a number of particular crash types appear in them, calling for a need to improve safety. Nonsignalised intersections represent potential hazards not present at signalised intersections because of the priority of movement on the main road. Vehicles stopping or slowing to turn create speed differentials between vehicles travelling in the same direction. The presence of traffic lights allows for a reduction of the conflicts between vehicles. While frontal-lateral accidents are typical in nonsignalised intersections, head-on and lateral collisions are more frequent in signalised ones.

The number of people killed or injured in road accidents depends basically on the three factors: exposure, accident rate and injury severity [1].

Exposure denotes the amount of activity in which accidents may occur. Any human activity is exposed to the risk of accident, but as far as road traffic is concerned, the amount of activity usually refers to the amount of travel, that is, the number of person-kilometre of travel performed.

Accident rate is the risk of accident per unit of exposure and is an indicator of the probability of accident occurrence. Although an accident rate is not identical to an estimate of probability, it is a useful indicator as the probability of accident occurrence, in the theoretical sense, can be assumed to be proportional to the accident rate. The higher the accident rate, the higher the probability of an accident on a given trip of a given length. The

probability of accident occurrence is affected by a very large number of risk factors related to the elements of the traffic system: infrastructure and traffic control devices, vehicles and road users.

Injury severity refers to the outcome of accidents in terms of injuries to people or damage to property.

In principle, there are four ways of reducing the number of persons killed or injured in road accidents:

- By reducing exposure to the risk of accident, that is, by reducing the amount of travel
- By shifting travel to means of transport that have a lower level of risk
- By reducing the accident rate for a given amount of travel
- By reducing accident severity, that is, by protecting people better from injury, or reducing affordably vehicle speed

When dealing with new means of transport like ARTS, the focus in terms of potential road safety improvement is mainly related with the second and third ways.

An ARTS has intrinsically a lower level of risk compared with other means of transport (it combines advantages of passenger buses with the use of technologies strongly reducing the risk of errors) [2]. Fig. 2.23 shows relative injury rates, in which the injury rate of a car driver has been set 1.0 [3]. The risk of injury travelling by passenger buses is half compared with cars and even lower compared with other transport's means.

A large number of risk factors have been found to be statistically associated with accident rates, that is, with the number of accidents per unit of exposure. One of these risk factors relates with the type of road or traffic environment. The rate of road accidents, given as accidents per million vehicle-kilometres of travel, varies greatly between different types of road and different types of traffic environment. An international comparison is given in Table 2.4 [3]. Motorways have the lowest risk of injury accidents

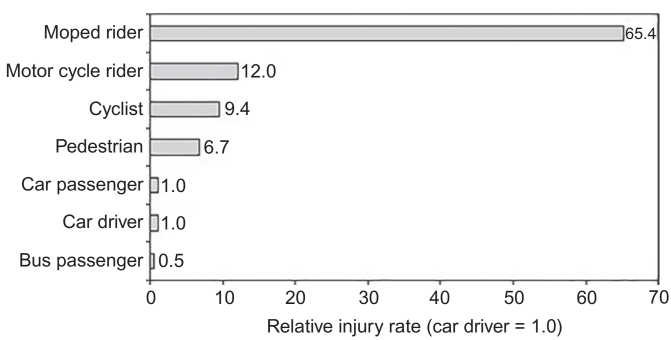

Fig. 2.23 Relative injury rates for different means of transport—mean for five countries.

Table 2.4 Relative risk on different types of roads in different countries—injury accidents (risk on motorways = 1.00)

Type of road	Denmark	Finland	Germany	The United Kingdom	Norway	The Netherlands	Sweden	The United States
	Rural areas							
Motorway	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Main road	3.97	2.91	3.00	2.82	2.28	1.33	1.29	2.72
Collector road	4.67	3.27			3.46	3.67	2.34	4.56
Access road	5.67	6.11		5.11	5.53	7.17	1.34	8.66
	Urban areas							
Main road	11.00	7.86		7.17	5.22		2.15	5.68
Collector	9.11	6.82		6.46	6.46	18.33	3.96	5.61
Access road	9.98	7.35		7.06	12.13	9.50	3.09	8.81
All	4.61	3.75	5.33	4.42	4.04		2.22	4.64

of all roads. All roads in urban areas have a higher rate of injury accidents than the average for public roads. The relative accident rate on access roads in urban areas is on average around seven, when the rate on motorways is set equal to one.

The design of roads can be described in terms of number of lanes, lane width, horizontal and vertical alignment, design of intersections and numerous other elements. In urban areas, accident rate increases as road width increases, mainly due to differences in speed, and the mix of traffic using the road may be compared with rural roads. The number of intersections and access points has a major impact on accident rate. At intersections, the accident rate increases if an intersection has more legs and if a higher proportion of traffic enters the intersection from the minor road.

According to the European Road Safety Observatory [4], in 2014, about 26,000 people were killed in road accidents throughout Europe, at least 5000 of whom were killed in road accidents at intersections (a reduction of more than 40% since 2005, following the trend in all fatalities). The proportion of fatalities in road accidents at intersections of all fatalities was slightly above 20% throughout the period from 2005 to 2014, meaning that, despite the decreasing trend in road fatalities, the issues related with traffic accidents in intersections have still a significant weight. As an average, within the EU, the fatality rate in intersections is equal to 11 fatalities per one million inhabitants.

The elderly (at least 65 years old) are more likely than others to be killed at intersections. The proportion of pedestrians in intersections fatalities has been steadily increasing in the last years (from 2005 to 2014) (Fig. 2.24).

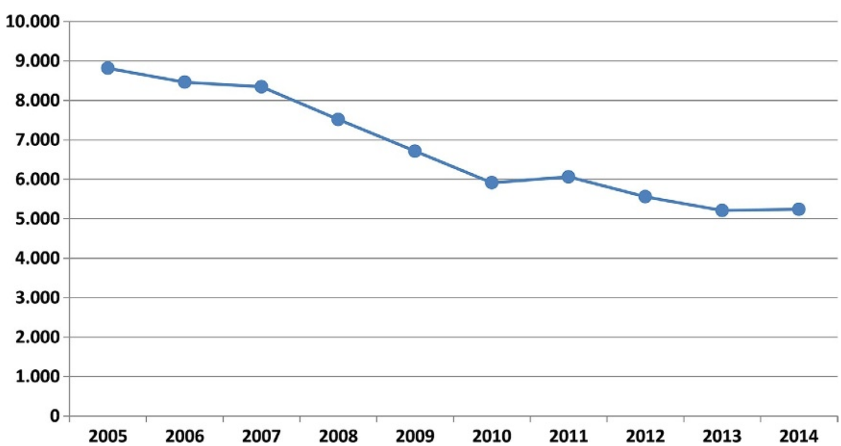

Fig. 2.24 Number of junction fatalities, EU, 2005–14. *(Source: CARE.)*

Intersections are major sources of traffic accidents in urban environment. This is true for all groups of road users [5]. In Rome, for instance, more than one-third of traffic accidents occur in intersections; according to the Rome open data for 2016, about 10,600 traffic accidents occurred in intersections, corresponding to about 34.5% of all traffic accidents. More than 70% of accidents in intersections occurred in nonsignalised intersections (about 7500 traffic accidents).

This paper deals with the road safety assessment of signalised and nonsignalised intersections and the potential impacts of the introduction of ARTS schemes. It comes after the three-step ARTS stepping out on the stage of the urban mobility, where the first step is represented by the ARTS dimensioning for last-mile transport reported in Ref. [6], the second step is represented by ARTS speed profile definition reported in Ref. [7] and the third step is represented by ARTS urban integration, whose general principles are reported in Ref. [8]. The aim is to provide preliminary information on how ARTS can be introduced in typical urban environments (signalised and nonsignalised intersections in this case) and on the potential benefits that can be expected in terms of traffic accident reduction. The paper also provides preliminary information on traffic-flow changes as a consequence of ARTS introduction and cost-benefit ratio.

The paper is organised into six sections. After the introduction, Section 2.4.2 deals with common methodologies for road infrastructure safety assessment and provides practical information on typical risk factors in signalised and nonsignalised intersections for different categories of road users. Section 2.4.3 deals with ARTS insertion schemes in nonsignalised intersections. It especially explains through a practical real-life example how ARTS can be introduced. Section 2.4.4 deals with ARTS insertion schemes in signalised intersections (also in this case, a practical real-life example is presented). Section 2.4.5 deals with the main barriers to the ARTS introduction and their expected impacts on safety and mobility. Conclusions and recommendations close the paper (Section 2.4.6).

2.4.2 ROAD SAFETY ASSESSMENT AND TYPICAL RISK FACTORS OF SIGNALISED AND NONSIGNALISED INTERSECTIONS

Road infrastructure safety management (RISM) procedures are effective and efficient tools to help road authorities to reduce the number of accidents and casualties, because design standards alone cannot guarantee road safety in all conditions [9].

Tools and procedures for a proactive approach to RISM already exist. For instance, in the European Union, RISM is legally specified in Directive 2008/96/EC of the European Parliament and of the council—particularly for road infrastructure on the Trans-European road network [10].

Different methodologies are identified in the directive: road safety impact assessments (to understand the implications on the road network safety of different planning alternatives of road infrastructure projects), road safety audits (to be carried out in planning, design and early operation stages of road development), safety ranking and management of road network in operation, *periodic inspections of the road network*, management of accident data and adoption of guidelines. These procedures have been proven to be effective in reducing road accidents and injury risk.

Among the existing RISM procedures, supporting road safety improvement in different stages of road development and road safety inspection (RSI) are normally used for road maintenance and renewal, for error correction and hazard elimination. RSI is a preventive methodology consisting of a regular, systematic, on-site inspection of existing roads carried out by trained safety expert teams. They result in a formal report on road hazards and safety issues identified, usually requiring a formal response by the relevant road authority.

The RSI procedure usually consists of the following consecutive steps:

- Preliminary analysis of information (e.g. traffic accident data, designs, traffic and mobility data), allowing to identify the main aspects influencing road safety (e.g. road users' categories most involved in traffic accidents).
- Execution of inspection by at least two inspectors, travelling the road or the intersection in different conditions (e.g. day/night, by car or by foot). The aim is to identify the main road infrastructure issues that could contribute to a traffic accident and their risk level.
- Preparing a report on the inspection explaining the identified issues, providing recommendations for possible road safety improvements and identifying priorities.

Road safety inspections are common practices in some European countries (especially in the United Kingdom, where RSI is systematically realised on most of the existing roads). Some case studies of RSIs on signalised and nonsignalised intersections have also been realised in Rome in 2014.

The analysis of traffic accidents in nonsignalised intersections has shown that the most involved vehicles are cars and powered two wheelers (PTW),

accounting together for more than 90% of accidents. Also pedestrians are involved in a significant percentage of accidents. Typical dynamics are frontal-lateral accidents. Typical risk factors, related with the categories of road users involved in traffic accidents in nonsignalised intersections (i.e. PTWs and pedestrians), are high speed, low visibility, vulnerability and protection devices and environmental factors.

To improve road safety conditions in nonsignalised intersections, typical solutions are thus connected with reduction of traffic-flow speed and improvement of visibility conditions. A number of possible infrastructural road safety measures exist in the literature to deal with these factors, for instance,

- introduction of traffic lights (transforming a nonsignalised intersection into a signalised one),
- removal of obstacles limiting the visibility,
- improving/maintaining traffic signs and signals,
- installing raised pedestrian crossings and intersections,
- installing rumble strips,
- creating channelisation.

The analysis of traffic accidents in signalised intersections has shown (like for nonsignalised intersections) that the most involved vehicles are cars and PTW, accounting together for more than 90% of accidents. Thanks to the presence of traffic lights reducing conflicts between road users; the traffic accidents involving pedestrians in signalised intersections are less frequent than in nonsignalised intersections (7.5% of total accident is average). The same appears for frontal-lateral collisions. The most frequent traffic accidents in signalised intersections are lateral collisions and head-on collisions (in average, respectively, 34% and 18% of traffic accidents). The presence of traffic lights increases the probability of sudden braking of vehicles and as a consequence head-on collisions. Lateral collisions are high due to higher probability of lane changing (traffic lights are typical in larger roads with higher speeds).

To improve road safety conditions in signalised intersections, typical solutions are connected with reduction of traffic-flow speed and lane changing. Possible infrastructural measures refer, for instance, with creating channelisation, reducing speed limits, improving signals and signs to advice about the presence of traffic lights and creating advanced stop zones for PTWs.

Other road safety measures can also complement the infrastructural ones, such as road safety campaigns, enforcement, training and education.

2.4.3 ARTS INSERTION SCHEMES IN NONSIGNALISED INTERSECTIONS

Within this section, a practical example of ARTS insertion scheme in a nonsignalised intersection is presented. Especially, an intersection inside the city of Rome is used as case study to assess how ARTS could be introduced and what benefits can be expected in terms of traffic flow and road safety. A RSI of the intersection has been realised in 2014, highlighting different road safety issues that could be efficiently solved also thanks to the introduction of an ARTS.

The nonsignalised intersection is composed of four legs. One leg of the intersection (via Ozanam) has one carriageway, two directions and one lane per direction. The other one (via Catel—via Fabiola) has one carriageway, one direction and one lane. Parallel parking slots are present on both sides of the roads. On via Ozanam, close to the intersection, bus stops are also present. Being a residential area, usually traffic flows are not significant, while pedestrian flows are important. Fig. 2.25 shows some pictures of the intersection: an aerial overview and the point of view of vehicles approaching the intersection from via Ozanam and from via Fabiola (equal to Via Catel). The current intersection configuration is shown in Fig. 2.26.

An analysis of traffic accidents occurred in the intersection, realised using data collected by municipal police during 8 years (from 2005 to 2012), showed that 63 accidents caused the injury of 61 road users. Most of the accidents occurred during daytime. Cars and PTW were the vehicles more

Fig. 2.25 Overview of the nonsignalised intersection.

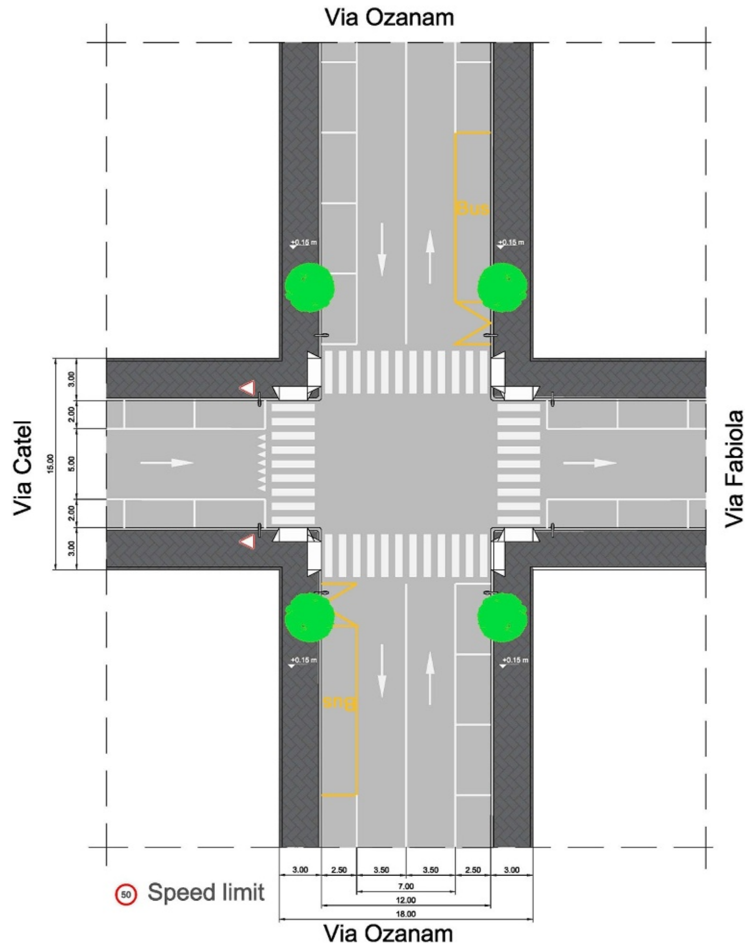

Fig. 2.26 Current scheme of the nonsignalised intersection.

frequently involved in traffic accidents. Accidents with pedestrians are also frequent (significantly higher than the average values in Rome).

Based on the results of RSI, the main risk factors within the intersection appear to be connected with the low visibility conditions, due to the presence of various obstacles close to via Catel. Currently, the road safety conditions seem not be adequately guaranteed by the absence of traffic lights, while the road characteristics and the design configuration would justify the introduction of traffic lights in order to manage conflicts between vehicles and with pedestrians.

Specific road safety issues and recommendations for improvements are summarised in Table 2.5. Qualitative risk levels connected with the road safety issues are also included.

Table 2.5 Specific road safety issues inside the nonsignalised intersection

Location	Safety issue	Recommendations	Risk level
Via Catel	Low visibility for drivers and pedestrians due to the presence of parked vehicles and obstacles (e.g. billboard) close to the intersection	SHORT TERM: parking slots close to the intersection should be removed SHORT TERM: obstacles should be removed MEDIUM TERM: footpaths could be advanced close to the intersection to avoid illegal parking of vehicles MEDIUM TERM: introducing traffic lights	High
Via Ozanam	Slides for wheelchairs and tactical paths for blind people are not adequately designed	SHORT TERM: slides and tactical paths should be redesigned and rebuilt	Medium
Via Ozanam	Parked vehicles and obstacles oblige buses to stop along the lane, without approaching the footpath	SHORT TERM: enforcement from police forces against illegal parking MEDIUM TERM: remove bus stops from the intersection area	Medium
Via Ozanam	The direction signal before the intersection is broken and not visible due to vegetation	SHORT TERM: change the signal and remove vegetation	Medium
Via Catel	Vehicles turning right and left from via Catel tend to stay on two lanes, due to the carriageway width	SHORT TERM: signs on the road should be adjusted MEDIUM TERM: introducing traffic lights	High

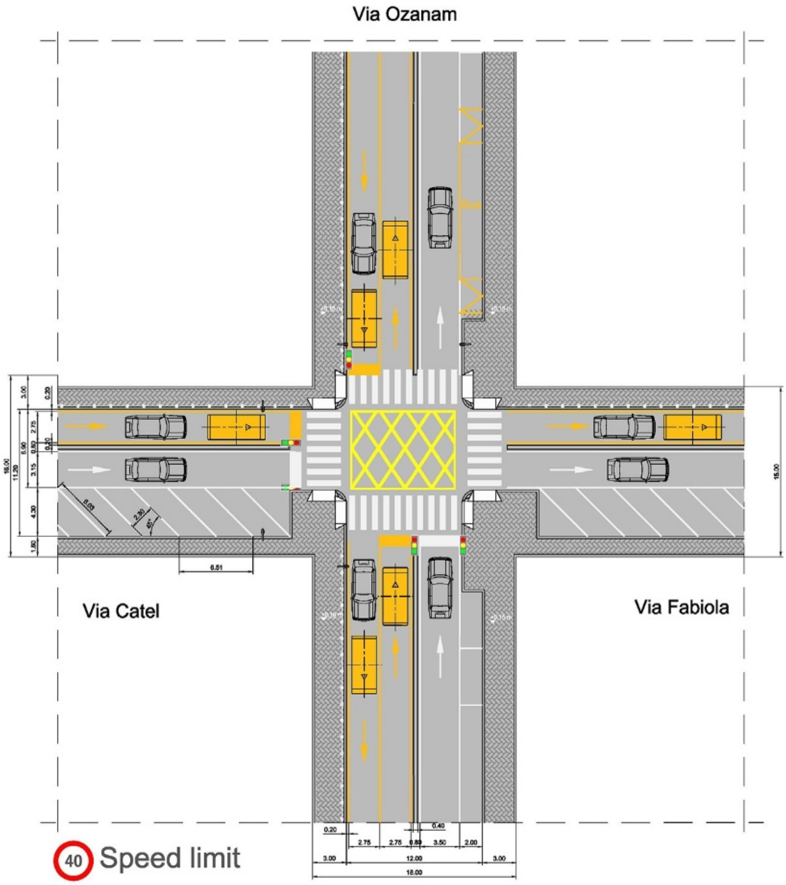

Fig. 2.27 Insertion scheme of ARTS in a nonsignalised intersection.

Based on the current road configuration, a possible insertion scheme of ARTS is shown in Fig. 2.27. The new scheme entails the following:

- Upgrade from nonsignalised to signalised intersection.
- Reduction of speed limits from 50 to 40 km/h.
- Reduction of the number of parking slots along the roads, in order to allow the creation of additional lanes for ARTS and conventional vehicles. The reduction of parking slots is justified by the presence of ARTS in the urban area, as alternative means of transport compared with cars.
- Conversion of parallel parking slots into diagonal parking slots, on one road.
- Elimination of bus stops on one side of the road (where ARTS travel). This choice is justified since ARTS offers more possibilities for door-to-door trips, rather than fixed stops [11].

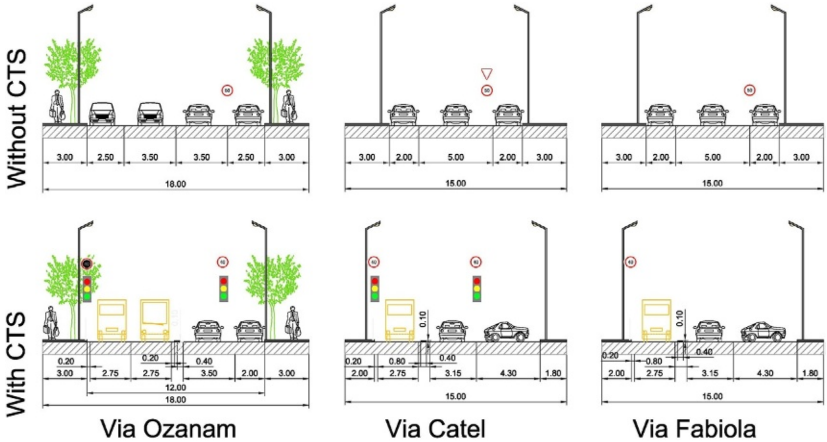

Fig. 2.28 Comparison of the nonsignalised intersection with and without ARTS.

As shown in Fig. 2.27, ARTS are not fully segregated; conventional vehicles can use the 'ARTS lanes'. On both roads, one of the lanes is dedicated to conventional vehicles and cannot be used by ARTS. ARTS lanes and conventional ones are physically separated. The intersection area can be marked to increase visibility (different configurations are possible depending on national regulations).

Fig. 2.28 shows the horizontal sections of the roads composing the nonsignalised intersection without ARTS (current road configuration) and with the insertion of ARTS. The insertion of the nonconventional transport means is clearly a matter of land-use reorganisation. Creating additional lanes for ARTS is similar to the creation of bus lanes, with the advantage that less space (width) is required for ARTS, so that impacts on conventional transport modes (and on traffic flows) are limited.

2.4.4 ARTS INSERTION SCHEMES IN SIGNALISED INTERSECTIONS

Within this section, an example of ARTS insertion in a signalised intersection is described. An intersection in the city of Rome is considered with the aim of assessing impacts of ARTS on road safety and traffic flows. A RSI has been implemented in 2014, whose results are described below.

The signalised intersection has four legs, composed of viale Regina Margherita and via Morgagni. Both the roads have high levels of traffic flows and more than one lane per direction. On viale Regina Margherita, a tram lane is also present in both directions. On via Morgagni, a lane

dedicated to buses is present in both directions. There are bus stops close to the intersection, on the four legs. Turning left manoeuvres are forbidden on the whole intersection, while all the other manoeuvres are allowed.

The intersection is in a residential urban area, and there are different shops. Traffic flow is generally high in the whole intersection, with high speed of vehicles. A high number of pedestrian can also be registered, due to the presence of bus and tram stop and of the metro. The intersection is practically a multimodal exchange area. Fig. 2.29 shows an overview of the intersection with the location of traffic accidents. The current intersection configuration is shown in Fig. 2.30.

An analysis of traffic accidents occurred in the intersection, realised using data collected by municipal police during 8 years (from 2005 to 2012), showed that 111 accidents caused the injury of 105 road users. Most of the accidents occurred during daytime. Cars and PTW were the vehicles more frequently involved in traffic accidents (accounting for 52% and 41% of the traffic accidents, respectively). Traffic accidents with PTWs are significantly higher than the average values in Rome. Also accidents involving pedestrians are frequent and significantly higher than the average values

Fig. 2.29 Overview of the signalised intersection.

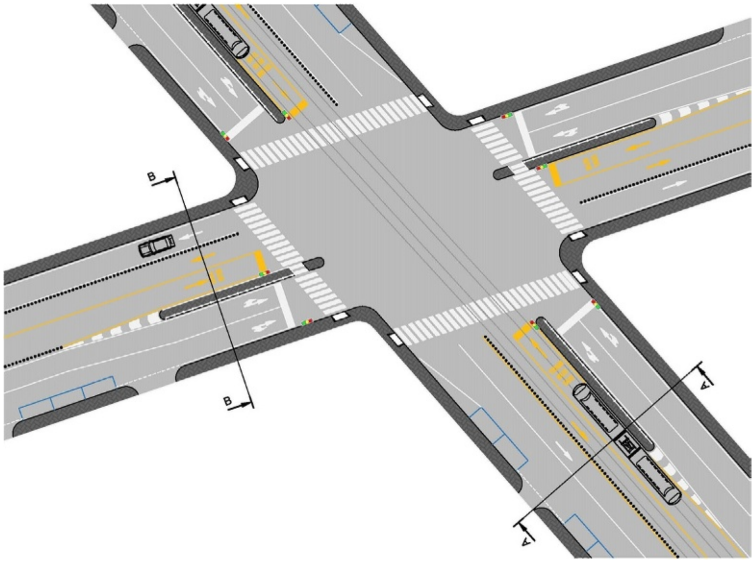

Fig. 2.30 Current scheme of the signalised intersection.

in Rome. Referring to type of collisions, the lateral accidents represent a high portion of the total, even if not significantly higher than the average values in Rome.

Based on the results of RSI, the main risk factors within the intersection appear to be connected with poor conditions of pedestrian facilities (e.g. pedestrian crossings and small islands) and with large road section and high speed of vehicles. Also the presence of bus and tram lanes is a potential risk factor.

Specific road safety issues and recommendations for improvements are summarised in Table 2.6. Qualitative risk levels connected with the road safety issues are also included.

Based on the current road configuration, a possible insertion scheme of ARTS in the signalised intersection is shown in Fig. 2.31. The new scheme does not entail major changes in the current infrastructural configuration. The ARTS simply use the already existing bus and tram lanes (and stops). This has practically no impacts on traffic flows (since no reduction of road capacity for conventional vehicles is foreseen). On the contrary, the new scheme increases the public transport capacity, since a new public transport mean (ARTS) is added. The presence of traffic lights guarantees the correct

Table 2.6 Specific road safety issues inside the signalised intersection

Location	Safety issue	Recommendations	Risk level
Viale R. Margherita	The island at the tram stop is too narrow, not sufficient for the number of pedestrians waiting for the tram. Wheelchairs cannot access the tram stop	SHORT TERM: enlarging the island and installing pedestrian barriers	High
All roads	Traffic signs are cancelled or not visible. Traffic signals are wrongly placed and could provide wrong information to road users	SHORT TERM: revising the whole traffic signs and signals in the intersection area in order to provide correct information and adequate visibility standards	Medium
Via Morgagni	The road pavement has numerous holes that could be dangerous for PTWs	SHORT TERM: refitting the road pavement in the whole intersection	Medium
All roads	The road's width and configuration allow the vehicle to drive at high speed, especially when traffic flows are low	SHORT TERM: introducing traffic calming measures allowing to reduce vehicles' speed MEDIUM TERM: designing a new road configuration providing more space to pedestrians and public transport means	High
All roads	Infrastructural solutions for disabled road users (e.g. paths for blind people and slides for wheelchairs) are inadequate or not present	SHORT TERM: refitting the solutions for disabled road users according to the international standards	Medium

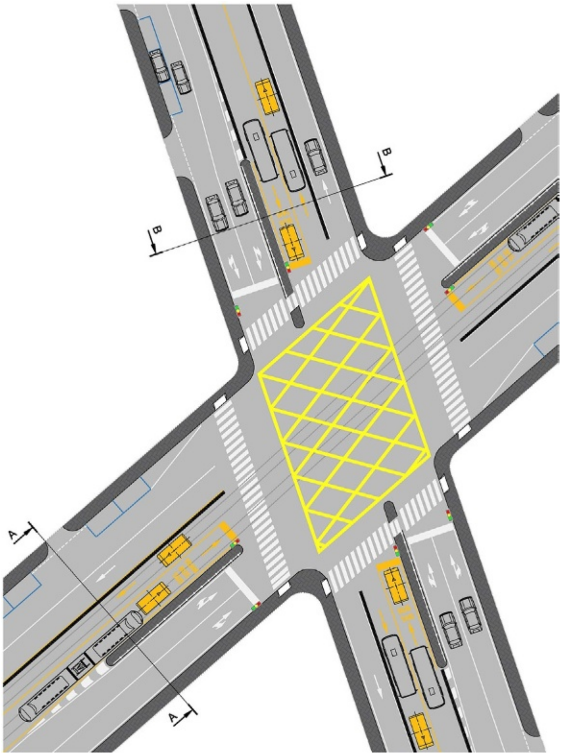

Fig. 2.31 Insertion scheme of ARTS in a signalised intersection.

functioning of the nonconventional vehicles. As shown in Fig. 2.31, in this case, ARTS is segregated from the conventional vehicles. Only the buses and trams share lanes with ARTS. The intersection area can be marked to increase visibility (different configurations are possible depending on national regulations).

It should be noted that the proposed insertion scheme is the simplest possible, allowing to add ARTS with few infrastructural changes. In the proposed scheme, the only change is related with refitting of road pavement in the whole intersection area (and especially in the ARTS lanes), in order to guarantee the operational conditions of the autonomous vehicles. Refitting of road pavement was also a recommendation issued from the RSI. The other road safety measures identified could anyway be implemented even with the ARTS in place. Especially, increasing width of islands for pedestrians at bus/tram stops would be important.

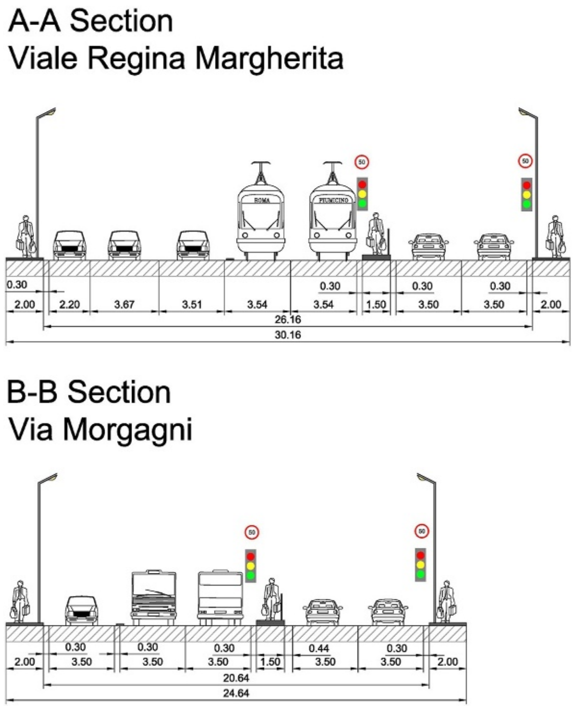

Fig. 2.32 Longitudinal profile of the signalised intersection.

Fig. 2.32 shows the longitudinal profiles of the roads composing the signalised intersection. The profiles are identical with and without ARTS. No impacts on conventional transport modes (and on traffic flows) are thus expected.

2.4.5 EXPECTED IMPACTS

2.4.5.1 Nonsignalised Intersections

The integration of ARTS on nonsignalised intersections has several potential benefits on road safety, due to the introduction of infrastructural measures having positive impacts on reduction of traffic accidents.

The integration of ARTS entails the introduction of traffic lights, which impacts on traffic accident reduction, which is significant. Traffic signal control at intersections separates different streams of traffic from each other and can improve the flow of traffic. According to Ref. [3], traffic signal control can reduce of about 30% the number of injury accidents and of about 35% the number of property-damage-only accidents, and the cost-benefit ratio of this solution has been estimated to equal to 8 (taking into consideration

building and environmental costs, saved costs for reduced travel times and reduction of accidents' social costs).

The new configuration of roads with the introduction of lanes shared between ARTS and 'normal' vehicles entails the introduction of channelisation. A full channelisation with marking was found to reduce of about 57% the number of accidents, while the physical channelisation at X-junctions was found to reduce of about 20% the number of injury accidents and of about 35% the number of property-damage-only accidents [3].

The new road configuration due to the ARTS introduction also entails some traffic control measures for pedestrians: raised crosswalk, lighting at crosswalks and pedestrian guardrails. The following impacts on road safety can be expected due to the introduction of these solutions:

- Raised crosswalk against ordinary marked crosswalk: 42% less injury accidents
- Lighting at crosswalks: 63% less accidents
- Pedestrian guardrails: 29% less pedestrian accidents and 8% less vehicle accidents

It should be noted that the insertion scheme described above entails the presence of diagonal parking slots that are less safe compared with parallel parking. The transition from diagonal parking to parallel parking was found to reduce the number of accidents of about 35% [3]. Using diagonal parking slots, on the contrary, allows to compensate the reduction of the total number of slots due to the creation of additional lanes on the roads. Alternative schemes (e.g. using only parallel parking) are also possible, depending on the specific cases.

One could argue that the ARTS insertion scheme could have a negative impact on traffic flow and, as a consequence, on congestion and environment. However, the difference in terms of traffic flows with the current scheme is rather limited for different reasons:

- The traffic speed reduction can be limited. For instance, in the proposed scheme the speed is reduced to 10 km/h. Using other speed limits is also possible, as well as using different speed limits on conventional lanes and on ARTS lanes.
- Generally, ARTS will absorb part of the road users that nowadays travel by car. A modal shift can be expected in favour of ARTS, so that congestion issues will be limited. This also has an impact on parking demand (i.e. lower in the scheme with ARTS).

2.4.5.2 Signalised Intersections

Potential benefits on road safety of ARTS's insertion are linked with infrastructural changes. In the basic insertion scheme described previously, the main change is related with refitting of road pavement. According to

Ref. [3], a reduction of about 4% of injury accidents can be estimated. Cost-benefit analysis of reasphalting shows that the ratio is positive and increases with the traffic volume (with an AADT equal to 7000, the cost-benefit ratio is about equal to 2).

The proposed insertion scheme can also be complemented by other road safety measures, such as

- increasing of pedestrian island width (which can have a significant impact on pedestrian accidents),
- refitting of disabled road user infrastructures (paths for blind people and slides for wheelchairs),
- improvement of signs and signals (a decrease of 15% of injury accidents can be expected from this measures, with cost-benefit ratio that can arrive up to 100 [3]).

2.4.6 CONCLUSIONS AND PERSPECTIVES

The paper has shown how the insertion of ARTS in intersections can provide significant benefits in terms of road safety, while not impacting significantly traffic flows. Most of the infrastructural solutions that need to be implemented when inserting an ARTS can be expected to reduce the number of traffic accidents and of injured road users. These assumptions are strongly supported by literature reviews and studies.

When comparing signalised and nonsignalised intersections, clear differences appear in the easiness of ARTS insertion and in the potential road safety impacts. Nonsignalised intersections need more interventions to allow the insertion of nonconventional transport means. Usually, nonsignalised intersections are used on roads with lower traffic-flow levels compared with signalised ones. Roads composing the intersection are usually narrow, which creates difficulties in inserting ARTS. However, the example provided in the paper clearly shows that difficulties can be overcome by just paying attention to a better land use. On the other hand, the insertion of ARTS in nonsignalised intersections seems having a higher potential of traffic accident reduction compared with signalised ones. This is quite normal since noncontrolled intersections entail more conflicts between vehicles and other road users (e.g. pedestrians).

When dealing with signalised intersections, it clearly appears that inserting ARTS is easier (and cheaper) since it requires fewer interventions (e.g. traffic lights are already in place). The potential towards traffic accident reduction is generally lower than nonsignalised intersections. However, the

typical kind of accidents is also different in signalised intersections, often linked to lane changing and speeding. The presence of ARTS has the potential to impact these kinds of risk factors.

In the future, when ARTS will become an integral part of the urban contexts, the various considerations and analysis on impacts (not only on road safety but also on traffic flows) will be probably revised. Even if the literature considerations on impacts of infrastructural measures can be considered very reliable, the specific impacts in different contexts (e.g. different countries or regions) could be different. However, the aim of this paper was only to provide an overview of the potential of ARTS towards road safety in intersections (i.e. the most dangerous locations in urban environments for road users).

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CHAPTER 3

Evaluation of Automated Road Transport Systems in Cities

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CHAPTER 3.1

The CityMobil2 Evaluation Framework

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3.1.1 INTRODUCTION

Congestion, land use, safety and environmental issues caused by high car-ownership and usage rates are the main challenges that European cities are facing to make mobility more sustainable. Large European cities in particular have adopted approaches based on a combination of efficient public transport services with access restriction measures to address these issues in city centres. Nonetheless, the use of private cars largely prevails in their suburban areas and in smaller cities. A key issue is how to provide an integrated door-to-door public transport service in such areas, capable of being implemented to encourage sustainable modal and support those without access to a car. The automatic road transport system (ARTS) developed and demonstrated in CityMobil2 can contribute to such a solution [1].

An evaluation framework was produced to provide evidence as to the credibility, form and implementation strategy for ARTS from a series of demonstrations. The demonstrations covered a range of scenarios to show the vehicle and service capabilities that allowed evidence to be collected on ARTS impacts.

The evaluation framework for an automated road transport system such as that implemented in CityMobil2 may be considered to fall under four headings (starting from a general methodology):

- Ex ante evaluation
- First assessment of users' attitudes towards automation
- Monitoring vehicle and system performance
- Understanding attitudes and behaviours of users and other stakeholders
- Determining the impacts on those in contact with the vehicles/system
- Appreciating economic and financial implications for implementation strategies

At each of the demonstration sites, evaluations may be comparative or absolute. Comparative evaluations would include factors such as a modal change from car to public transport, induced by an enhanced attractiveness in one or more elements of the new automated service. Factors such as vehicle reliability or the interactions between automated vehicles and pedestrians are unique to the new system, although some comparisons can

be made with more conventional existing systems. Evaluation results may also be compared between demonstrations, so as to add a richness of understanding from the range of application contexts. The distinction between large and small demonstrations was based on their duration and the number of vehicles used: large demonstrations lasted longer and used larger vehicle fleets. The main evaluation findings came from the large demonstrations.

A major success of the CityMobil2 project has been the development of commercially viable automated vehicles and management systems. At the start of the project, no suitable automated vehicles were available, and the demonstrations that were made during the project incorporated increasingly sophisticated vehicles and systems, which were deployed as they were developed. This complicated the cross site evaluations, as those sites using more advanced vehicles projected rather different views to users and others whilst being fundamentally similar in operation. Thus, whilst the evaluations in CityMobil2 follow the same framework and content, the comparative analyses across the demonstrations were somewhat compromised by the evolutionary development of the vehicles/system and by the application contexts of the different cities. Nonetheless, the evaluation framework formed a credible basis for identifying the effects and effectiveness of automated road transport systems. Indeed, the variations in vehicles, systems and application contexts enabled a fuller understanding of the characteristics needed for success.

Whilst the six evaluation areas are introduced separately below (one per section), soon after a section dedicated to a brief description of the whole methodology, it is to be noted that they are not uniquely separated. For example, the frequency and character of technical failures will impact on attitudes and behaviour and financial returns.

3.1.2 THE METHODOLOGY ADOPTED FOR ARTS EVALUATION

In the CityMobil2 project, 12 cities have prepared a local study on the implementation of an innovative automated road transport system. Based on this study, each city provided a proposal to host an automated road transport system demonstrator. The city proposals were ranked demonstrator by demonstrator to select seven of these cities to implement the demonstrators in the second phase of the project.

The city study design, evaluation and selection methodology reported in this document is directly derived from the MAESTRO guidelines [2] and adapted to the CityMobil2 aims. Fig. 3.1 shows a general diagram of the methodology.

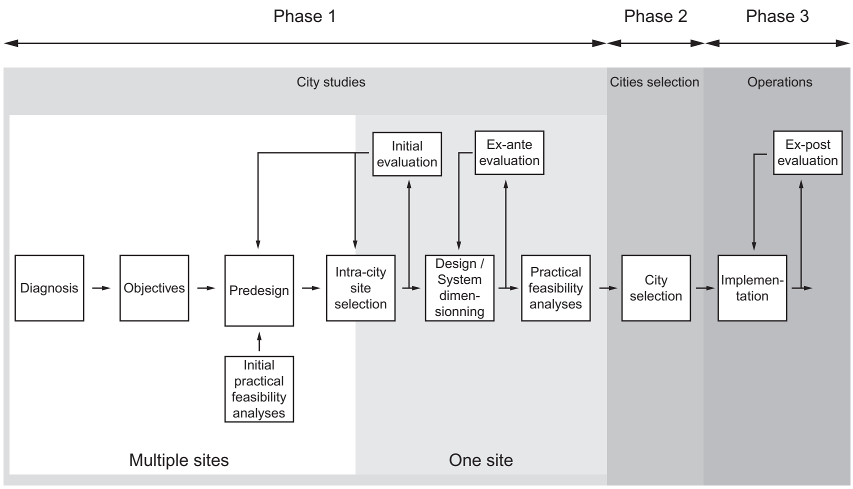

Fig. 3.1 Design, evaluation and city selection methodology.

The methodology was divided into three phases:

- Phase 1: to which all the 12 cities participated
- Phase 2: resulting in the city selection
- Phase 3: carried on by the seven selected cities (for the implementation), ex post evaluated in the project final phases

The city study design, evaluation and selection methodology steps are briefly explained below and further detailed in the next sections. Each step has precise inputs and outputs, which are indicated at the beginning of the corresponding section:

- Diagnosis: This preliminary step consists of the analysis of the political and planning context of the city making the study and of the analysis of the local problems that could be solved with the introduction of the ARTS.
- Definition of the objectives and impacts: This step is based on the analysis of local and regional objectives and allows the identification within each city of several potential sites where to implement the transport system and host the ARTS, other than the choice of a set of expected impacts to be taken into account for the evaluation of the system.
- Intracity site selection: The main outcome of this step is the selection of one single site in each city. In order to do that, it is necessary to carry out a predesign of each of the potential sites, in order to have a first quantitative estimation of demand and supply for each of them. Each city is free to choose the methods to obtain these results. Once demand and supply are quantified, experts can help identify which impacts the new system

will have. A first check on the practical feasibility criteria (stakeholder support, financial support, ...) can be useful to avoid selecting a site that might turn to be not suitable to host the ARTS. Both impact expectation and practical feasibility analyses can provide feedback on the predesign and allow, if necessary, an iteration to provide some modifications.

- Initial evaluation: This step consists of the selection of a set of indicators as common base for the evaluation of the ARTS. The list of the indicators used in the project is provided; some of them are 'core indicators' and should be always measured to have a detailed evaluation. A reference case should be defined for each indicator in each city and a threshold for success.
- Design: In this step, the demand is foreseen with a quantitative method, the system is dimensioned and correctly integrated in the existing urban environment, the awareness campaign is designed, and the costs of the ARTS are quantified.
- Ex ante evaluation: The data related to the indicators selected in the initial evaluation should be collected, then evaluated and compared with each indicator's reference cases and thresholds for success.
- City selection: Ten criteria have been adopted to rank the proposals in the project, regarding legal, technical, financial, management (including communication and awareness raising) and governance aspects of the city. However, not all the criteria can be quantitatively measurable (e.g. stakeholder involvement, interest groups and reactions); such criteria could be a valid framework for the final evaluation of the ARTS to be implemented. An audit visit can be useful to check that all the practical criteria are respected.
- Implementation and ex post evaluation: These steps regard the system operations and are briefly summarised on the basis of the project experience. Ex post evaluation is based on the indicators chosen for the ex ante evaluation and is compared with it to see whether the ARTS fulfil the expectations or not.

3.1.3 EX ANTE EVALUATION

The ex ante evaluation of an ARTS defines the expected impacts that an ARTS could have on the mobility, in terms of users attracted, transport performances, financial incomes and outcomes, technological improvements, socio-economic relevance and environmental impacts.

To define such impacts, four evaluation areas have been considered:

- Transport system
- Economic efficiency

- Environmental impacts
- Safety and security

Each evaluation area has two or more subcategories, named evaluation categories, with the exception of the safety and security area. The evaluation categories chosen for the CityMobil2 project are as follows:

- Acceptance
- Quality of service
- Transport patterns
- Social impacts
- Environment
- Financial impacts
- Economic impacts

Each evaluation category includes different impacts.

The indicators for the ex ante evaluation have been derived from previous projects (MAESTRO and CityMobil); a set of 65 indicators as reported in Table 3.1 have been provided.

A suggested minimum set of 23 indicators have been highlighted in grey and reported ** before their name.

In the evaluation framework, such 23 indicators have to be considered as mandatory, in order to allow the ARTS ex ante evaluation to comprise all the categories established.

The remaining indicators are useful to have a more detailed evaluation of the expected impacts of the system.

3.1.4 FIRST ASSESSMENT OF USERS' ATTITUDE TOWARDS AUTOMATION

One of the aims of the research within CityMobil2 is to relatively assess automation with respect to conventional bus services in terms of users' attitudes.

Users' attitudes towards automated buses are largely unexplored. Most of the studies in the available literature (often grey literature) investigated the potential demand on specific routes [3–5]. Only a few studies aimed to assess the relative preferences of the users towards automated versus a conventional bus. One took place in Leeds [6] and one in Rome [7]. Both were based on stated preference (SP) data. Personal rapid transit has been the subject of other studies [6,8–10].

In CityMobil2, SP data, based on questionnaires administered in the cities participating in the project, have been used for the estimation of discrete choice models (logit models) providing preference shares for the conventional and the

Table 3.1 Set of impacts and indicators for the CityMobil2 project

Evaluation category	Impacts	Indicators	Description of indicator	Unit of measure
Acceptance	User acceptance	Usefulness		
		Ease of use		
		Reliability		
		User satisfaction for the on-demand service		
		**Integration with other systems		
	Willingness to pay	**User willingness		
		Authority willingness		
Quality of service	Information	Availability		
		Comprehensibility		
	Ticketing	User satisfaction		
	Cleanliness	Perceived cleanliness		
	Comfort	**Perceived comfort		
	Privacy	Perceived level of privacy		
	Perception of safety and security	Perception of safety		
		Fear of attack		

Continued

Table 3.1 Set of impacts and indicators for the CityMobil2 project—cont'd

Evaluation category	Impacts	Indicators	Description of indicator	Unit of measure
Transport patterns	Modal change	Induced mode changes in the other segments of the journey	Percentage of trips made by other modes complementary to the system	%
		**System modal share	Percentage of trips made by the new system	%
	System use	**Total passenger·km travelled	Average total passenger·km travelled per day	pkm/day
		**Total N° of trips	Average total number of passenger trips per day	trips/day
	System performances	**Vehicle occupancy	Mean number of people per vehicle	pax/veh
		Average journey time per OD pair	Average in-vehicle time to complete a specified journey	min
		Journey time variability	Standard deviation of average journey times per OD pair	min
		Total delay per trip	Travel time exceeding the minimum travel time requested to cover a trip	min
		**Average waiting time	Mean waiting time at the stops for vehicle to arrive	min
		Waiting time variability	Standard deviation of waiting times	min
		Interchange time	Time to change between modes	min
		**Effective system capacity	Maximum possible number of passengers	pax/veh

Social impacts	Spatial accessibility	**Change in range of key activities accessible within time thresholds	People accessing to a key activity in a given time threshold	%
		Distribution of accessibility changes by social group	Changes in accessibility for different social groups	%
	Service accessibility	Access times for mobility impaired users	Time taken for a mobility impaired user from the vehicle arriving to the passenger boarding	sec
	Safety	Accident levels	Number of accidents per year	nr./year
		Incidents	Mechanical failures that could affect the systems and cause accidents	nr./year
Environment	Energy	**Daily consumption	Average daily vehicle consumption of energy	kWh
		**Energy efficiency	Energy used for passenger per kilometre	kWh/pkm
	Toxic emissions	NO_x	NO_x emissions per kilometre	g/km
		PM_{10} and/or $PM_{2.5}$	Small particulate emissions per kilometre	g/km
		CO	Carbon monoxide emissions per kilometre	g/km
	Climate change	CO_2	Carbon dioxide emissions per kilometre	g/km
	Noise	L_{den} and L_{night}	LA_{eq} where evening and night-time levels are given a penalty of 5 and 10 dB, respectively	dB
	Land take	Loss of green space from construction	Change in green space resulting directly from the construction of the system	km^2
		**Change in road space availability to other users		
		Total land-use change	Change in green space within the city	km^2

Continued

Table 3.1 Set of impacts and indicators for the CityMobil2 project—cont'd

Evaluation category	Impacts	Indicators	Description of indicator	Unit of measure
Financial impacts	Startup costs	**Track construction and civil works	Investment for track and civil works	€
		**Vehicle acquisition/construction	Investment for the vehicle	€
		**Control systems and apparatus	Investment for the control systems	€
	Operating cost revenues	**Personnel	Yearly cost of the personnel	€/year
		**Vehicle maintenance	Vehicle yearly costs	€/year
		**Track and civil infrastructure maintenance	Track yearly costs	€/year
		**Control system maintenance	Control system yearly costs	€/year
		**Operating revenues	Total yearly system revenues	€/year
Economic impacts	Temporary job provided by installation and demonstration	**Jobs provided at the demonstration site	People working in the demonstration	Person-years
		Jobs increase induced at the manufacturers	Working people increased due to the demonstration	Person-years
	Long-term effects on jobs	Local effects on employment	Temporary and long-term jobs provided by the installation and operation of the system	Person-years
		Nonlocal effects on employment	Access opened up new jobs in neighbouring areas and access opened to outsiders taking local jobs	Person-years
	Efficiency	**Financial net present value	Final result of financial cost-benefit analysis	Index
		**Socio-economic net present value	Final result of socio-economic cost-benefit analysis	Index
		**Internal rate of return	Alternative approach to the net present value (NPV)	Index
		**Benefit/cost ratio	Alternative approach to the NPV	Index

automated bus. Two sets of surveys have been planned: one ex ante, with individuals without actual experience of the automated bus, and one ex post, with individuals who travelled on board the automated bus during the demonstrations.

The ex ante surveys have been part of the feasibility studies, concerning the implementation of a small-scale automated bus service and conducted in 12 cities. The routes of the feasibility studies include a range of applications:

- Within city centre (La Rochelle, Oristano, Reggio Calabria and Trikala)
- Within a major facility such as a technology park or a university (CERN, Lausanne EPFL, San Sebastián and Sophia Antipolis)
- From public transport node to a major facility (Brussels, León and Milan)
- From public transport node to a residential area (Vantaa)

The ex post surveys have been conducted in four cities that have been selected, on the basis of the feasibility studies, for demonstration of the automated bus service: La Rochelle, Trikala, Lausanne EPFL and Vantaa.

For comparability between cities and between ex ante and ex post results, a common SP questionnaire has been designed.

3.1.4.1 The SP Questionnaires

In questionnaires based on SP data [11], interviewees are asked to express their preference in hypothetical scenarios. Each scenario is identified by values of the attributes characterising the transport alternatives. Values of the attributes are chosen in order to obtain the variability of each attribute needed for estimation. The combinations of the values of the attributes giving rise to the different scenarios are chosen, in the standard methodology referred to as orthogonal design, to minimise colinearities.

The questionnaire of the ex ante survey includes the following parts. First, the route of the public transport service under planning is described. A brief description of two vehicle options, a conventional minibus and an automated minibus, is provided. It is specified that the two vehicles are equal in terms of propulsion and of total and seating capacity. Both run in mixed traffic. The difference is the presence or absence of the driver. In the second part of the questionnaire, respondents are asked to choose between a conventional minibus and an automated minibus in different supply scenarios for a trip of given length. The supply scenarios for the services provided by the two vehicles are defined according to different levels of waiting time, riding time and fare. These are the relevant service quality attributes from the users' point of view. The third part relates to the personal characteristics of the respondents: gender, age, income before taxes, education, occupation, car availability in the household and ownership of a public transport monthly ticket. An example questionnaire is shown in Table 3.2.

Table 3.2 Example questionnaire of the ex ante survey

	Minibus (with driver)	**Automated vehicle (without driver)**
Scenario 1		
Waiting time (minutes)	8	3
Riding time (minutes)	5	5
Fare	As other public transport means	Extra fare of 2 EUR for a return journey
Q2. Which one would you choose?	☐	☐
Scenario 2		
Waiting time (minutes)	8	8
Riding time (minutes)	10	10
Fare	As other public transport means	Extra fare of 2 EUR for a return journey
Q3. Which one would you choose?	☐	☐

Scenario 3		
Waiting time (minutes)	3	3
Riding time (minutes)	5	10
Fare	As other public transport means	As other public transport means
Q4. Which one would you choose?	☐	☐
Scenario 4		
Waiting time (minutes)	3	8
Riding time (minutes)	10	5
Fare	As other public transport means	As other public transport means
Q5. Which one would you choose?	☐	☐

Limited modifications are included in the questionnaire of the ex post survey where questions are referred to the actual trip made.

Details on the SP design for the ex ante and the ex post survey are included in the chapter 'Assessing automation on transport demand' of this book.

3.1.4.2 The Econometric Models

Discrete choice models [12–14] are econometric models based on random utility maximisation. The following assumptions are made:

- The individual chooses the alternative with maximum utility.
- The modeller is not able to know with certainty the utility of the individual who makes the choice; therefore, he represents the utility by a random variable, usually expressed as the sum of a systematic part and an error term.

Discrete choice models produce the values of the probabilities that each alternative is chosen by each individual. The shares of the alternatives are obtained by aggregation of individual probabilities.

Discrete choice models are classified based on the assumption related to the probability distribution of the error terms. The model used in CityMobil2 is the popular multinomial logit. The marginal distribution of the error terms is extreme value type 1, also known as Gumbel distribution. Error terms are distributed identically and independently across alternatives. In multinomial logit, choice probabilities have closed-form expressions. To estimate the coefficients of the attributes that appear in the systematic part of the utilities, the method of maximum likelihood is used.

The use of discrete choice models estimated on SP data is nowadays a common practice in transportation analysis [11,13]. One of the key advantages of SP data is the generation of multiple responses per interviewee. In the standard application of the model estimation, all observations are treated as statistically independent. This is, however, a limitation with multiple observations by the same respondent.

The econometric models provide comparisons between the cities and between the ex ante and ex post cases regarding

- the weights of the factors influencing choices;
- the statistical significance of the factors;
- the monetary values and associated willingness to pay of individual attributes of the transport system.

The factors influencing choice that have been considered include

- the attributes of the transport system (such as travel time—respectively waiting and riding—and fare);

- the modal constant of the automated bus, representing the mean of all the other attributes, including automated driving, not appearing in the systematic part of the utility;
- the socio-economic attributes of the users.

As far as willingness to pay is concerned, the aim has been to explore the magnitude of the willingness to pay for a system-specific fare, that is, an extra fare, for the automated bus.

Details on the econometric specification of the models estimated in CityMobil2 and of the related results are included in the chapter 'Assessing automation impact on transport demand' of this book and in Ref. [15]. Refs. [16,17] present the methodology and results of the estimation, on the same SP data, of advanced logit models that have taken into account correlation across observations.

3.1.5 MONITORING VEHICLE AND SYSTEM PERFORMANCE

Overall, the monitoring of the vehicles and the system was intended to

- develop an appreciation of the vehicle operating conditions to help interpret related attitudes and behaviour, for example, the effect of jerk on perceived passenger comfort;
- assess the operating performance of the vehicles and system, for example, vehicle reliability and comparing actual with desired speed profiles;
- assess the current and likely maintenance costs over the lifetime of a system;
- help identify opportunities and issues for upscaling;
- record passenger numbers and movements and for the grooms to administer questionnaires.

Three data sets were needed for the vehicle, the vehicle operator/groom and the system operator. (Groom was generally the term used for the individual who had to ride in each vehicle for safety reasons.)

Each vehicle was required to carry a 'groom' to meet essential safety requirements. Their role was to intervene in the event of a perceived risk, to restart a stopped vehicle, to operate it where necessary (usually at the terminal point on the route or where the route has been blocked) and to administer questionnaires. The intention was that the grooms would have a low profile, so that the vehicles would be clearly seen as being automated by both passengers and those external to the vehicle. Whilst this potentially compromised the concept of full automation to varying extents across the demonstrations, grooms were able to identify and collect information

on events, either recorded by the vehicle system, such as an unexpected braking action, or not recorded by the system, such as a door malfunction. Particularly, they were able to monitor the number and activities of passengers. Grooms recorded their information on a tablet. Grooms were observed to act differently in the different demonstrations, but throughout, there was an emphasis on the vehicles being driven by the automated system.

Vehicle data relate to all its functions such as speed, acceleration, sensor records, system override and location. An accurate time stamp is important to link vehicle data to events identified across sensors and in other databases. In CityMobil2, the time stamp agreed was one-tenth of a second. At typical speed of 5–10 m/s, this represented a movement of no more than 1 m. A key issue is the potentially huge amount of data, and this was addressed differently at different stages of the project. A decision was made to monitor but only record a window of 10 s before and after an event identified by a groom. During the course of the project, the laser systems on the vehicles and the associated software were improved substantially.

The system operator organised the monitoring and charging of vehicle batteries, maintenance and vehicle availability and condition more generally. In the first large demonstrator (La Rochelle), this was a fairly simple process, with considerable input from the manufacturer to address faults. Later, in Lausanne, a sophisticated computerised central system was in place that logged activities, vehicle data and locations in real time.

It is to be noted that the main use of vehicle monitoring data in the project was to provide feedback for the continuous development of the vehicles, so that they could evolve into a sound finished and marketable product.

3.1.6 UNDERSTANDING ATTITUDES AND BEHAVIOURS OF USERS AND OTHER STAKEHOLDERS

The CityMobil2 project demonstrated an innovative approach to the solution of urban traffic problems. The level of innovation was such that the system and underlying concepts were novel to most people in the demonstration cities. The large demonstrations in particular provided a substantial opportunity for users and other stakeholders to experience the potential of such system in practical environments. This in turn enabled valuable evidence to be collected on attitudes and behaviours. Three sets of surveys were conducted that addressed users, the wider public and stakeholders/decision-makers, each of which is discussed in turn below.

3.1.6.1 User Surveys

The ex post user evaluation survey aimed to

- collect information on user's mobility behaviour and their level of satisfaction with the ARTS service, as well as their socio-economic characteristics;
- provide system designers with recommendations for improvement in system characteristics;
- assess user's perception of safety, security and emergency management and their willingness to pay and assess whether experience and, depending on the awareness campaign carried out, information altered attitudes towards ARTS.

These objectives were addressed by carrying out two separate surveys of ARTS users:

- Ex post evaluation questionnaire for users. The first survey was specifically designed to collect information on the ARTS users' mobility behaviour and their level of satisfaction with the system.
- Ex post stated preference (EPSP) questionnaire for users. The second survey was designed to collect information on the possible changes in attitudes towards the ARTS due to having experienced the system and being informed by awareness-raising campaigns and to collect information on users' willingness to pay and their perception of safety, security and emergency management on board the ARTS.

A single survey would have extended the time required to complete the questionnaire beyond the average user's limit of tolerance. The downside was that two separate samples of ARTS users were obtained.

The ex post evaluation questionnaire was used to interview users face to face on exiting ARTS at stops or online to be filled out by users at their own convenience. The people targeted were users of the ARTS system, and the survey was anonymous to address privacy issues. The questionnaire was preceded by a filter question to avoid interviewing the same person more than once. Other questions were organised according to the following subjects:

Awareness. The question relating to awareness allowed the effectiveness of the information campaign deployed in the city to be assessed.

Trip. This part included questions about the interviewee's current trip, which naturally included the use of the ARTS service. A trip was defined as a journey with a specific origin, destination and purpose, which was not necessarily limited to the ARTS mode. The first group of questions were concerned with the characteristics of the trip, whilst the second group of questions were focused on the trip experience on the ARTS.

Satisfaction. The questions included in this part of the questionnaire were designed to collect information on both the level of satisfaction with the ARTS and the importance attributed to the different quality indicators. The quality indicators were grouped into five categories (usefulness, integration with other modes, level of service, comfort and information). These were referred to as macrofactors. Three out of five macrofactors (level of service, comfort and information) were broken down into a number of microfactors, which helped to understand the factors in a more precise way.

Personal information. This part of the questionnaire included questions on socio-economic information (gender, age, level of education, occupation, income, nationality and handicaps).

The EPSP questionnaire survey of users was carried out using either online questionnaires or interviews, depending on the individual demonstrator site organisation. The people targeted were users of the ARTS system, and the survey was anonymous to address privacy issues. The questionnaire was structured into several sections preceded by a filter question to avoid interviewing the same person more than once.

The first section, 'Experience with the ARTS', assessed users' perception of safety, security and emergency management. The last two aspects were investigated only if the member of the on-board operating staff, that is, the 'groom', had not been identified.

In the section 'Willingness to pay' (WtP), users' WtP for the ARTS service was assessed with reference to the then-current public transport fare in a scenario in which the ARTS service experience would be converted into a permanent service.

The section 'Future utilisation' investigated attitudes towards ARTS services in the city in terms of whether or not an ARTS service should run permanently on the ARTS route demonstrated or elsewhere in the city.

For the section 'Stated Preference', the user was initially asked to declare their perceived travel time on board; then, for four different scenarios, the user was asked to choose between two different transport options (ARTS and conventional minibus) operating on a frequency basis (not on-demand), offering the same service in terms of route and stops and using the same vehicles in terms of propulsion (electric-powered), design and capacity. Each scenario was described in terms of the three variables extra fare, waiting time at stops and riding time each assuming two different values as shown in Table 3.3 below.

Table 3.3 EPSP design—attribute and levels

Alternative	Attribute	Number of levels	Levels
Minibus/ARTS	Waiting time	2	Waiting time/2*waiting time (minutes)
	Riding time	2	Perceived riding time/0.8*perceived riding time (minutes)
	Extra fare	2	Current PT fare/extra fare

The section 'Socio-economic characteristics' included questions on information useful to characterise the users sampled in terms of gender, age, level of education, occupation and handicaps.

The SP data collected were used to estimate discrete choice models based on multinomial logit probability functions. Common marginal utilities of waiting time, riding time and fare across the two alternatives were used in all specifications. Therefore, denoted by numbers 1 and 2, the conventional minibuses and automated minibuses (i.e. ARTS), respectively, the specifications of the systematic utilities were

$$\begin{aligned} V_1 &= \beta_1 \cdot \mathrm{WT} + \beta_2 \cdot \mathrm{RT} + \beta_3 \cdot \mathrm{FA} \\ V_2 &= \beta_1 \cdot \mathrm{WT} + \beta_2 \cdot \mathrm{RT} + \beta_3 \cdot \mathrm{FA} + \mathrm{ASC} \end{aligned} \tag{3.1}$$

Both alternatives included attributes of waiting time (WT), riding time (RT) and fare (FA). For ARTS, this was as other public transport or extra fare. The alternative ARTS also included an attribute specific constant (ASC).

The riding time variable assumes the values used in the EPSP questionnaire; for fare, the 'effect coding' −1/1 has been used (instead of 'dummy coding' 0/1 to avoid confusion with the ASC) with '−1' for an extra fare and '+1' for the same fare as other public transport.

The other model was built on the basic model, but its utility function also included one attribute related to a socio-economic characteristic (SE) of the users and the corresponding marginal utility:

$$\begin{aligned} V_1 &= \beta_1 \cdot \mathrm{WT} + \beta_2 \cdot \mathrm{RT} + \beta_3 \cdot \mathrm{FA} \\ V_2 &= \beta_1 \cdot \mathrm{WT} + \beta_2 \cdot \mathrm{RT} + \beta_3 \cdot \mathrm{FA} + \mathrm{ASC} + \beta_{SE} \cdot \mathrm{SE} \end{aligned} \tag{3.2}$$

The socio-economic attributes considered were

- Age is considered as cardinal variable. The average value has been assigned to each of the answer options (21 to the option '18–24', 29.5 to the option '25–34', 39.5 to the option '35–44', 49.5 to the option

'45–54', 59.5 to the option '55–64' and 69.5 to the option '65–74'), except for the first and last options (18 to the option 'under 18' and 74 to the option 'over 74').

- Education is considered as ordinal variable. The levels 1, 2, …, n have been assigned to each of the answer options starting from the lowest (1 to the option 'primary school', 2 to the option 'secondary school', 3 to the option 'university bachelor', 4 to the option 'university master' and 5 to the option 'PhD degree').
- Gender, for which effects coding has been used: 1 for male, and −1 for female.

The model with socio-economic variables allowed the assessment of the impacts of each variable on user preference. The t-test with a null hypothesis of a zero coefficient was adopted to assess the statistical significance of the attributes that appeared in the econometric specifications of the utilities of the t-test. The 5% significance level (two-tailed test) was considered, with 1.96 being the value of reference for the t-statistic.

3.1.6.2 Wider Public Survey

The objective of the survey was to develop a clear understanding of public opinions towards the implementation of automated vehicles in urban areas. Key questions to be answered included the following:

- How much of the public is aware of self-driving technology?
- How attractive would the implementation of automated vehicles in urban areas be to the public?
- What are the main public concerns relating to the implementation of ARTS in urban areas?
- What are public attitudes towards owning or sharing automated vehicles?

The survey involved 28 questions to address topics including the following:

- Public awareness and understanding about automated vehicles
- Attractiveness and concerns of automated buses
- Attractiveness and concerns of automated taxis
- Attractiveness and concerns of car-sharing applications
- Attitudes towards owning or sharing automated vehicles

The local survey teams identified different approaches, which were considered to be best able to generate a strong response. These are described in Table 3.4.

Table 3.4 A summary of survey methods used by the demo cities

City	Survey method taken
La Rochelle	The survey was undertaken following the completion of the demonstration of ARTS in La Rochelle. Two survey methods were used: an online questionnaire and phone interviews. Firstly, an online survey was conducted in May/June 2015 targeting people working/studying/living around the route of the automated buses demonstrated in La Rochelle. The survey was distributed through e-mails, advertised through flash codes and distributed physically at a number of attraction points such as shops/restaurants/media library/aquarium/tourist office—located in the neighbourhood of the demonstration route. A total of 148 people responded to the online survey. Subsequently, a telephone interview survey was undertaken during 1–17 July 2015 to reach people in the wider areas of La Rochelle. A total of 500 people were recruited to participate in the interview.
Lausanne	After the demonstration of automated buses in Lausanne, an invitation was sent to all campus users of Lausanne Engineering School (EPFL) in August 2015. The invitation was sent in e-mails that provided a link to an online questionnaire. A total of 586 people completed the questionnaire.
Vantaa	The questionnaire forms were distributed on August 5 by mail to all households in the Kivistö area of the city. In total, 1113 copies were delivered to households near the demonstration site. In addition, 200 questionnaires were distributed to all exhibitors of the housing fair. In total, 1313 copies were distributed. Respondents had opportunities to answer online using the instructions on the survey form or to return the paper copies of the survey in a prepaid envelope delivered with the survey. As a reward, 10 movie tickets were distributed to the respondents to increase levels of participation in the survey (selected by lottery). A total of 118 questionnaires were completed and returned with a response rate of 9.0%.
Trikala	The survey started in January 2016, 1 month after the start of the full implementation of the ARTS operation, and continued until the end of the demonstration on 29 February 2016. The questionnaire distribution was undertaken mostly by staff of e-Trikala, who were involved in the ARTS demonstration, and by the municipal office of volunteers who were trained by the e-Trikala staff. In order to ensure a fair representation of local people, residents were randomly sampled for participation in the survey. The questionnaires were distributed via a prepaid mail service to residents in both urban and suburban areas of the city. In addition, approximately 200 questionnaires were distributed to the staff and students of the city's technical lyceums and schools and to institutes of education and training. A total of 601 people completed and returned the questionnaire. Their responses were coded and input to an Excel file by e-Trikala staff. Some imbalances were found in the demographics of the sample; for example, there were too many females aged from 25 to 54. In order to remove the bias, the data were resampled taking into account the demographic distributions of age, gender and education of people in Trikala. When the sample distributions did not match the local demographic trend observed, the extra number of respondents was randomly removed. After this resampling, the responses from a total of 470 people were available for further analysis.

3.1.6.3 Stakeholder Surveys

The objectives were to assess stakeholder awareness and acceptance of the automated road transport system and the circumstances and extent to which they would actively consider or support an ARTS system. Key stakeholder groups considered included local transport authorities, urban planning authorities, public transport service operators, goods delivery service operators, the police, local resident groups (citizens associations, neighbourhood organisations, etc.) and manufacturers.

This survey addressed small relevant samples in each demonstration city but ensured coverage of relevant stakeholder categories with a range of 1–5 questionnaires each. The exact number depended on the number of relevant actors identified in each city per category, and the questionnaire was given to them 1 month before the end of the demonstration. In view of the very different administrative structures in the demonstration cities, there was some flexibility in the approaches, and some questionnaires were administered by interview and some in group sessions. This ensured that key decision-makers were involved. Questions covered the individual's role, their general knowledge of, and attitudes towards, automated vehicles, the city demonstration and potential future applications.

3.1.7 DETERMINING IMPACTS OF THOSE IN CONTACT WITH THE VEHICLES/SYSTEMS

The objective of this evaluation was to understand how other road users, particularly pedestrians and cyclists, interact with automated vehicles in an urban environment. Further objectives relate to understanding how the vehicles and system should evolve to improve actual and perceived safety and what should be avoided in a future system. Two surveys were undertaken.

One used structured interviews with small groups on site together with a questionnaire to a larger group administered electronically using an iPad or tablet. The people targeted were those seen to be interacting externally with the vehicles, that is, pedestrians and cyclists, randomly selected, but with a distribution of ages and a balance between sexes. The target sample size was 300, although this was never fully achieved. An attempt was made to have three phases of questionnaire covering the start, middle and end of the large demonstrations so as to be able to track evolutionary changes in attitudes and behaviour as the ARTS became more familiar.

Obtaining a good response rate for surveys of this nature is difficult, and the questionnaire length was kept to a minimum. The questions were

in two parts. The first contained a small number of essential demographic questions. This was followed by more specific questions regarding scenarios where the participants were required to imagine themselves in a particular scenario and report on the information they would require from the vehicle for a safe and productive communication and interaction with the vehicles.

An area of data collection that proved difficult was the use of vehicle mounted or roadside video cameras. Such data are particularly useful to monitor interactions between the demonstration vehicles and other road users, particularly pedestrians and cyclists. The use of video images of people proved to be a contentious issue of privacy, particularly with regard to the first large-scale demonstrator in La Rochelle. Eventually, a novel multicamera video system was introduced that provided automated output of pedestrian and cyclist interactions. The use of the system included rigid security protocols to safeguard privacy.

3.1.8 ECONOMIC AND FINANCIAL IMPLICATIONS

A cost-benefit analysis (CBA) was undertaken to understand the economic and financial implications of introducing an ARTS. This required the following steps:

- Develop one or more practical scenarios for the deployment of ARTS.
- Define a time horizon for the evaluation.
- Define an appropriate discount rate.
- Estimate operator costs and benefits over the life of the project.
- Estimate the social costs and benefits (e.g. reduction in accidents and emissions).
- Calculate the net present value.
- Undertake sensitivity assessments.

Considerable work was undertaken to develop scenarios for full-scale deployment within CityMobil2. They involved the physical aspects of routes, the level of service provision, the integration with other public transport services and the related traffic and transport policies. This is a complex area, as the attraction of a public transport service involving ARTS will also involve restraint measures applied to car movements. Indeed, the application of restraint measures to car traffic may only be politically acceptable with the introduction of ARTS to provide a sufficiently attractive alternative. Also, ARTS can provide a new local service, unavailable by any other means. There may be considerable benefits to a city by adding ARTS as an attraction for tourists. On the supply side, scenarios also include ticketing policy,

personnel involved and enforcement, whilst on the demand side, modal change and economic benefits are particularly difficult to estimate.

The selection of an appropriate time horizon for the economic analysis should relate to major investment periods. In this case, as the major cost of an ARTS is the vehicles, a life of 10–15 years was considered appropriate.

The discount rate, that is, the rate at which costs and benefits in the future are discounted to the present, was determined by consideration of European Commission guidance. The social discount rate (SDR) reflects the social view on how benefits and costs should be valued against present ones. As an economic analysis, it includes the costs to society of changes in factors such as accidents. The financial discount rate is defined as 'the expected return forgone by bypassing other potential investment activities for a given capital'. The discount rates used were those recommended in EC documentation at the time.

The most difficult area is that of estimating costs and benefits. An estimate of costs can be made by consideration of the vehicle, maintenance and running costs that have occurred during the demonstration, suitably modified to take into account the savings that would accrue in a more reliable full-scale system. These can also be compared with the costs of comparable systems. The largest change in practice would be the savings made when the system operates in a fully autonomous mode without a groom. In the demonstrations, the ARTS tended to operate as an additional system not strongly integrated with existing public transport operations. This limited the potential to measure modal changes and hence many of the benefits.

3.1.9 FINAL COMMENTS

With a radical new system such as ARTS, the challenge is to develop the maximum understandings at each stage of implementation, so that the subsequent stages can move forward positively and with confidence. It has not been possible to make a comprehensive operational, safety and economic case from the demonstrations. However, the evaluation framework has led to the building of blocks of knowledge that are sufficient to move to larger deployments that will test the ARTS as part of a comprehensive approach to a more sustainable transport. The evolution of the ARTS vehicles over the course of the project has been considerable, and the next stage of deployment should enable the full benefits to be quantified.

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CHAPTER 3.2

Evaluating ARTS in La Rochelle

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3.2.1 CITY DESCRIPTION

Located between Nantes and Bordeaux, on the French Atlantic coast, La Rochelle Urban Community is a medium-sized conurbation administratively attached to the Poitou-Charentes region and to the Charente-Maritime department. It is one of the most dynamic French territories in terms of population and image.

La Rochelle Urban Community comprises 28 municipalities around the city centre, La Rochelle (74,880 inhabitants). In total, its population amounts to 164,332 inhabitants (2013).

3.2.1.1 Background on the City and Participation to the Selection Process

La Rochelle was one of the 12 cities proposing to host a demonstration. Since the 1970s, even before 'sustainable development' was a well-known concept, La Rochelle was committed to the improvement of the quality of life: preserving open green areas, introducing the first pedestrianised streets in France in 1973 (Fig. 3.2), offering 'vélos jaunes' (self-service bike hire) since 1976 and even setting up selective recycling in 1995.

Fig. 3.2 A picture of two cyclists in the pedestrian street (1976).

Fig. 3.3 A picture of a pedestrian street during the car-free day.

In 1997, La Rochelle pioneered the first 'car-free day' (Fig. 3.3). At the turn of the century, it launched new projects and initiatives—notably a goods delivery service by electric vehicle, an electric car-sharing system and even solar electric shuttle boats to transport passengers across the city harbour. Traditionally receptive to exchanges and new ideas in the areas of mobility, urbanism and community life, La Rochelle ventured into European projects, mostly in the field of sustainable transport. Many of the experimentations are now fully integrated into the 'La Rochelle lifestyle'.

In La Rochelle, the first 'flavour' of automation in automated transportation was given by the showcase—within CityMobil project—that was given in September 2008 in the centre of the city (Fig. 3.4 shows a picture of the vehicle). This short-term demonstration—carried out on a closed circuit—had a strong impact on both La Rochelle's inhabitants and decision-makers. The objectives of this demonstration perfectly matched the political agenda of La Rochelle regarding innovation and clean mobility, that is, to keep La Rochelle at the forefront of innovation in transport and sustainable development.

This is why La Rochelle's decision-makers decided to continue the partnership with INRIA. A demonstration of fully automated vehicles in real-life conditions was organised in 2011. This demonstration was different from the first one as regards its ambition: the cybercars circulated for the first time in an urban open environment with interactions with pedestrians and cyclists; the tests and demonstration were carried out on a 3-month period.

Fig. 3.4 A vehicle picture during CityMobil project.

The vehicles encountered some failures but without any consequences on safety, thanks to the low speeds and the presence of an operator on board. The questionnaires that were carried out showed that the inhabitants believed in the development of such vehicles for public transport purposes in the future…

After this successful experiment, La Rochelle decided to go further and was proposed to participate in the CityMobil2 proposal and apply as a potential site for a demonstration.

3.2.1.2 The City Transport Problems

As described above, La Rochelle has been for long at the forefront of innovation in the field of mobility and transport and year after year has succeeded in offering a wide range of clean and soft mobility options for its population—notably electromobility ones.

Nevertheless, as an in-depth transport analysis was carried out in 2011 pointed out, the operation of public transport as a whole could be optimised. Indeed, the number of bus trips made by the inhabitant is rather

low. The modal share of collective transport and its use remains low despite an attractive supply for a city of this size. This is partly due to the lack of restriction on parking policies: finding a parking place with a private car is not considered as a problem. The journey times by public transport are not competitive enough with those by private cars.

The users of collective transport are in great part captive. The cycles allow an interesting alternative and more recreational use. The modal share of cycling is very high in La Rochelle city centre. In other parts of the town, the cycle, if facilities were provided, could meet the needs of internal trips.

The electric car-sharing system is rather little used. Its catchment area is limited to La Rochelle (no station—but one—is located outside the city centre) where the lack of constraints on parking makes the system still unattractive. The rate of car ownership remains therefore very high (80%). The park and ride facilities are also little used.

3.2.1.3 The Selected Site and Transportation Objectives

The main objectives of the public transport network are to develop the backbone transport links on the major axes of the first ring of La Rochelle and to implement P+R facilities at the end of these axes to provide less dense municipalities with an attractive offer of transport.

Those penetrating axes would also be reshaped to give them a more 'urban face' as the objective will be to stop the traffic further upstream.

Another objective is to have a better coordination between the transportation policy and the parking policy, notably by strengthening the constraints of parking in La Rochelle city centre.

The automated road transport system can complement and strengthen the new organisation of the public transport network based on structuring axis and park-and-ride facilities. Conventional public transport solutions would focus on the structuring axes, whilst the automated road transport system may allow offering a fine service within the territory.

Within La Rochelle city centre, the automated road transport system would help to increase the modal share of public transport and soft modes by providing a solution to and between large traffic generators, by increasing the attractiveness of public transportation, by completing the mesh and by focusing on intermodality.

By introducing ARTS in its public transportation system, La Rochelle expects to reinforce the efficiency and the attractiveness of the public transport. The collective transport network needs to be strengthened—especially the BRT lines. By offering a 'last-mile' option, ARTS would be

a perfect complement and reinforce the attractiveness of BRT lines. The ARTS has to be fully integrated into the transport public system, and the system has to be reliable and easy to use and to understand and has to meet a real mobility need.

3.2.1.4 The City Study Output: The Selection of a Route

The city study performed during the first phase of CityMobil2 project aimed at realising a detailed analysis of citizen's mobility needs in order to identify the existing deficiencies of the mobility chain supply that an accurate multimodal concept, involving an innovative transportation system, could answer to.

Several sites were identified on the territory of La Rochelle Urban Community for potentially hosting an automated road transport system—from the short to the longer term. Most of these sites with various mobility needs were still under development both in what concerns urban planning and transport system.

A cross comparison was made between the sites to determine the most likely to receive a demonstration in 2014–15. The main comparison criteria were the potential deployment horizon, the short-term technical feasibility and the visibility in order to raise awareness of the citizens on such systems.

For CityMobil2 experts, La Rochelle seemed to be—among the 12 potential sites—the most appropriate and ready location for implementing a large-scale demonstration.

Within La Rochelle city centre, several potential routes have been considered. La Rochelle city centre is a dense area that combines a variety of functions with many traffic attractors and generators. It is not always perfectly adapted to conventional public transport: short routes, multiple stops, various destinations.... The regulated zone and the narrow streets in the city center make it difficult for heavy buses to circulate. It imposes one-way streets, different routes to go back and complex crossings. It is however well suited for small automated vehicles. The demonstration route connecting La Rochelle central train station to the Technoforum in the Minimes district was the one selected in the study.

- It connected sectors with heterogeneous characteristics, demographically and functionally:
- The university sector, Media Library, University Library, Human Sciences University campus and its restaurant, and Technoforum (university, administrative offices, stores and conference rooms)

- The main train station sector (main access point for tourists and commuters from outside the city)
- The city centre, which hosts a high density of inhabitants and employments

3.2.1.5 The Final Demonstration Route

The CM2 ARTS system was demonstrated in La Rochelle city centre between 17 December 2014 and 25 April 2015. As mentioned above, the route was chosen because of its feasibility and because it was a central location, highly visible and easily accessible for people strolling in La Rochelle.

The route proposed initially included a leg between the main train station and the university (Technoforum) with six vehicles in exploitation. Due to technical delays in the delivery of the vehicles and incertitude on the operation of such a system through a park, in front of the train station, the local consortium decided first to phase the opening of the route. The period of operation was supposed to be from November 2014 to March 2015.

The on-site tests with an automated Robosoft vehicle started on 13 October 2014. Contrary to what was expected, these first test proved to be not robust enough for considering a quick implementation. The manufacturer was quite unexperienced in setting up ARTS systems in an urban environment. Considering the technical difficulties the manufacturer faced (only the GPS system was operating; the mix between the laser and the GPS was not yet ready), a decision was taken. The local partners, the manufacturer, with the support and approval of CM2 coordinator, decided to sequence the demonstration in several phases.

The idea was to start the demonstration by the 'easy' leg of the route—without waiting for all the problems to be solved for operating the service. Instead, an adapted service on first leg of the route (taking into account the limited number of vehicles available) was offered.

The step-by-step approach retained consisted in the end of three different phases:

- Phase 1: Aquarium—Motte Rouge from 17 December 2014 to 25 January 2015 (Fig. 3.5)
- Phase 2: Technoforum—Médiathèque from 26 January 2015 to 3 March 2015 (Fig. 3.5)
- Phase 3: Aquarium—Technoforum from 4 March 2015 to 29 March 2015 (Fig. 3.6)

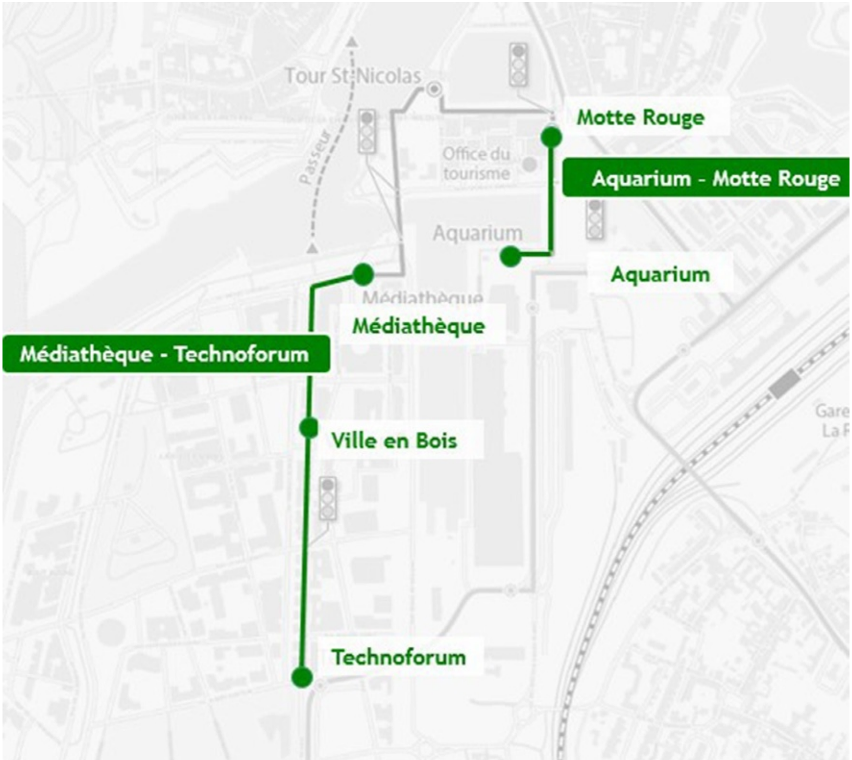

Fig. 3.5 Route planned for phase 1 and phase 2.

The fourth and last step (to the train station) has never been set up, according to an agreement between the manufacturer, the coordinator and the local partners. Too many technical uncertainties were still obvious and brought an important risk to degrade the operation of all other parts of the system.

In the end and overall, the route consisted in a 2.6 km circuit roundtrip—in the city centre of La Rochelle.

3.2.2 THE CityMobil2 DEMONSTRATION

3.2.2.1 Infrastructural Interventions

In order to ensure an efficient operation and also and more specifically to adopt a very safe approach, some adjustments of the roads were needed. Indeed and notably because La Rochelle was the first large-scale demonstration in CityMobil2 project, safety was a prerequisite and the most crucial criteria for the local partners.

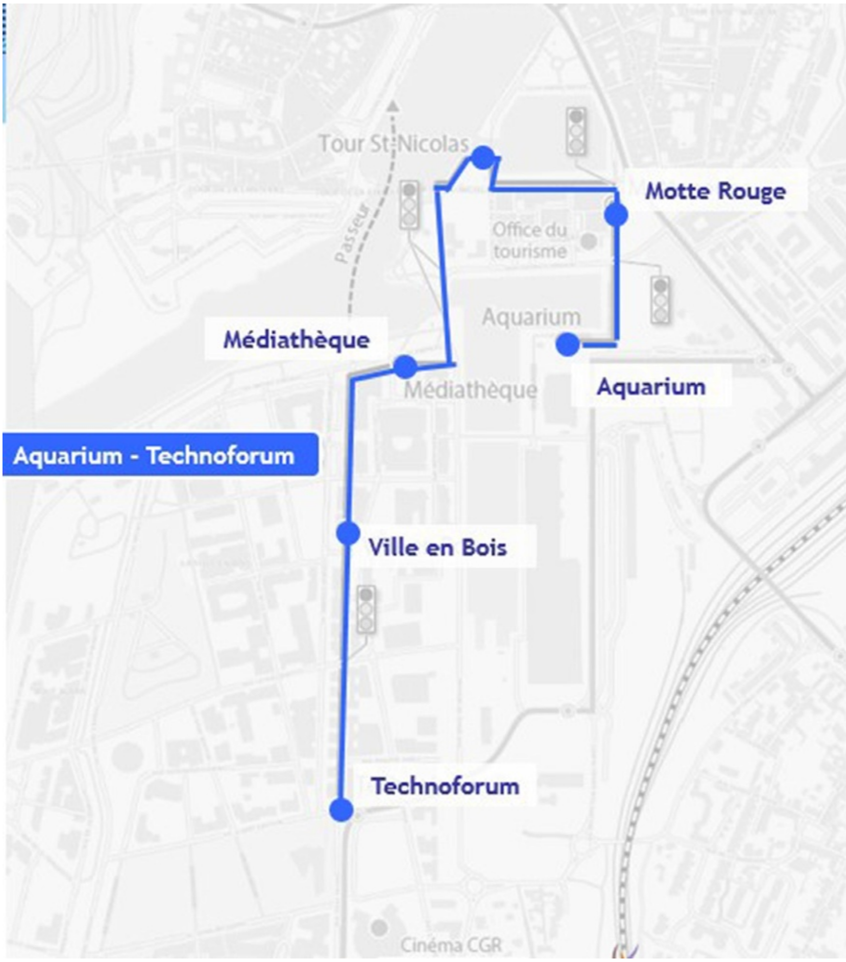

Fig. 3.6 Route planned for phase 3.

Without providing details, we can mention the following:

- Platforms/stations were designed, built and installed at each of the stop of the route design, building and integration of platforms/stations.
- Bollards/barriers were installed in order to restrict access for car.
- Traffic lights were installed at crossings giving the priority to the ARTS on the other vehicles.
- A significant number of uncontrolled on-street parking were removed.
- Road signs and road marking were needed in order to inform and warn the other users of the road of the presence of an ARTS experimentation.

3.2.2.2 Operational Aspects

Prior to the demonstration itself, efforts have been deployed to prepare the arrival of the vehicles, to assess the impact of the automated vehicles in the organisation of Proxiway's vehicle depot and to organise concretely the future operation—bearing in mind that deviations may occur from the initial plans in the real implementation.

The depot was equipped with additional and adapted electric plugs and metres in order to ensure the charging of the vehicles. A reorganisation and some works were needed to provide ARTS vehicles with an appropriate access. As the ARTS vehicles were located in the same depot as electric cars, electric vans and electric trucks, parking lots have been reorganised in order to facilitate the entrance/exit of the CityMobil2 vehicles.

One of the first tasks has been to anticipate and consider the number of operators that would be recruited for the demonstration—which proved to be quite a complicated task as the demonstration itself had to be adapted—as mentioned above a number of times and as a step-by-step approach was adopted in the end. Specific attention was paid on defining accurately the offer of the demonstration (time schedules and frequency) in order to calibrate this recruitment. Staff was recruited; reference planning table was designed. Then, the training of the staff started:

- Two *supervisors*—in charge of supervising the operators in their activities and the vehicles on the route—were recruited. They were first trained by the local partners (La Rochelle Urban Community, Robosoft, Proxiway and Eigsi). It was important for them to be able not only to identify the work to be accomplished in order to achieve their mission but also to have some knowledge on the automated vehicles, on the European project CityMobil2, to be able to answer most of the questions asked by the users.
- Five *operators*—that is, persons on-board vehicles in charge of stopping the vehicle or take it for a short time in manual mode in case of malfunction or deviation—were recruited. In the end, the tasks of the operators became far more than the one described. They were the main contacts with the users and provided obvious added value to the users in terms of information and awareness raising on the system.

3.2.2.3 Legal Aspects

As regards La Rochelle demonstration, the legal aspects were carefully looked at from the inception but in the end became a long-standing process. The authorisation to circulate was delivered by the transport minister only after nearly 1 year of discussions with the local state authorities (prefecture) and various directorates of central ministries (transport, home affairs and

environment/climate) and few exchanges with SRMTG—a national certification authority.

La Rochelle Urban Community and its partners prepared a significant folder describing all aspects of the demonstration (i.e. the whole system (vehicles + communication + infrastructures)) and the detailed specific route. Several delegations from the ministries came to La Rochelle for on-the-ground visits (before and during the demonstration).

In the end, La Rochelle's automated vehicles were delivered with plates (called 'W-plates') and were authorised (by derogation) to operate the automated vehicles (after some infrastructure adjustments and additional signs on the road) on the proposed route.

These visits and exchanges with ministries proved to be very beneficial as the delegates from the ministries expressed some useful recommendations for La Rochelle demonstration. The delegates became aware that the process for obtaining the authorisation for such an experimentation was complex and long and that legislation had to evolve at least to create a simplified legal framework for temporary experimentations such as the one carried out by La Rochelle within CityMobil2 (after La Rochelle's demonstration, in 2016, a decree was published to authorise such experimentations).

As regards insurance, the manufacturer Robosoft obtained from its insurance company the necessary legal guarantees to operate the automated vehicles they manufactured on La Rochelle's proposed circuit.

3.2.2.4 Communication and Awareness-Raising

La Rochelle partners implemented a series of dedicated information, stakeholders' consultation, awareness raising and communication actions towards La Rochelle inhabitants and beyond. These actions proved to be crucial to accompany the demonstration and contribute to its success:

- Significant efforts were made to meet a wide range of local stakeholders—directly or indirectly impacted by the ARTS experimentation—prior to the demonstration. It was much useful to anticipate the potential issues and find appropriate solutions with the stakeholders. Specific efforts were brought on keeping the population informed on the demonstration, and several articles were dedicated to CityMobil2 demonstration—in the local media and in the institutional magazine.
- A specific dissemination action targeted children from the primary school. La Rochelle partners worked on a special edition of *Le Petit Quotidien*—a newspaper dedicated for children aged 10. The edition was distributed to all pupils of every school of the territory (7000 exemplary sent to pupils of primary schools and 3000 exemplary to other kids).

3.2.3 ARTS OPERATION AND EVALUATION

The ARTS operation in the demonstrations has been evaluated on the basis of the CityMobil2 framework [1].

3.2.3.1 Technical Feedback

Incidents or technical failures of ARTS systems were recorded during the demonstration. During the experiment, all data have been collected by operators and consolidated by supervisors. Each operator used a data sheet in order to report all incidents or failures during trips.

These failures can be put into two main categories:

- Failures related to the system: For example, in February, the leg between 'Aquarium' and 'Motte Rouge' was under control, whereas the deployment of the second leg from 'Technoforum' to 'Médiathèque' generated a lot of problems. These problems were due to technology issues such as GPS or SLAM failures and organisational reason such as traffic modification.
- Failure related to the reliability of the vehicle itself: This is the case for mechanical failures that occurred more or less regularly throughout the demonstration. Weather influenced the performance of the vehicles. LASER sensors were disrupted when heavy rain fell. It was also noted that reflections of light from roadside furniture could interfere with the operation of the vehicles when the weather was sunny.

Analysis of speed and acceleration profiles of ARTS vehicles

During the demonstration, vehicle data were logged by Robosoft including vehicle and sensor data (e.g. speed, GPS and laser).

The results of the analysis demonstrated that automated vehicles were able to control speeds and accelerations/decelerations more accurately and consistently than human-driven vehicles. Users of automated vehicles would be expected to benefit from such improvements: reduction of accident rate and severity thanks to a strict limit of the speed; reducing fuel consumption and pollutant emissions, thanks to sudden acceleration/deceleration; smoother vehicle movements; and improved riding comfort to users.

From the data logged, automated control of the vehicles was the more usual situation. However, the on-board operator had to intervene relatively frequently (7.5% of the running time).

3.2.3.2 User Interviews on Acceptance and Quality of Service

User interviews on acceptance and quality of service were carried out face to face during different demonstration periods (at the beginning, February

2015, and at the end of the project, April 2015). Respondents were randomly selected among the user's on-board automated vehicles or shortly after getting off at a station. Over the two waves (at the beginning and the end of the project) of the survey, 310 users participated in surveys.

Different types of information were collected from the survey of users:

- Their levels of awareness of the system in order to assess notably the effectiveness of the information campaigns
- Information on their experiences with ARTS and trip characteristics
- Their feedback on the quality of the service offered

3.2.3.2.1 ARTS Awareness

As mentioned above, communication campaigns and awareness raising on CityMobil2 project began early. However, about half of the respondents (49%) became aware of the demonstration by chance. The local media (31%) were more popular for the users aged 65–74. Seven percent of respondents declared having used an automated vehicle during the previous CityMobil1 demonstration that took place in the city of La Rochelle in 2011.

3.2.3.2.2 Experience With ARTS

The proportion of people having used the system more than once increased from 21% to 37% between the two waves. This variation provides some useful information to understand the adoption process of the system by users during the demonstration. Of the people surveyed (both waves included), approximately 70% of the people only used the system once, with 40% of them from La Rochelle and 28% from outside La Rochelle urban area. The most frequent purpose of the ARTS trips (62%) was curiosity ('just to travel using ARTS').

Typical age ranges in this category were 35–44 and 55–64 years old. During the demonstration period, this category of users started to have some habits concerning the use of ARTS.

The Satisfaction and the Quality of the Trip

The questionnaire was designed to collect information on both the level of satisfaction with the quality of the ARTS and the importance they attribute to the different quality indicators.

The quality indicators were grouped into five categories:

- Usefulness
- Integration with other modes
- Level of service: on-board waiting time

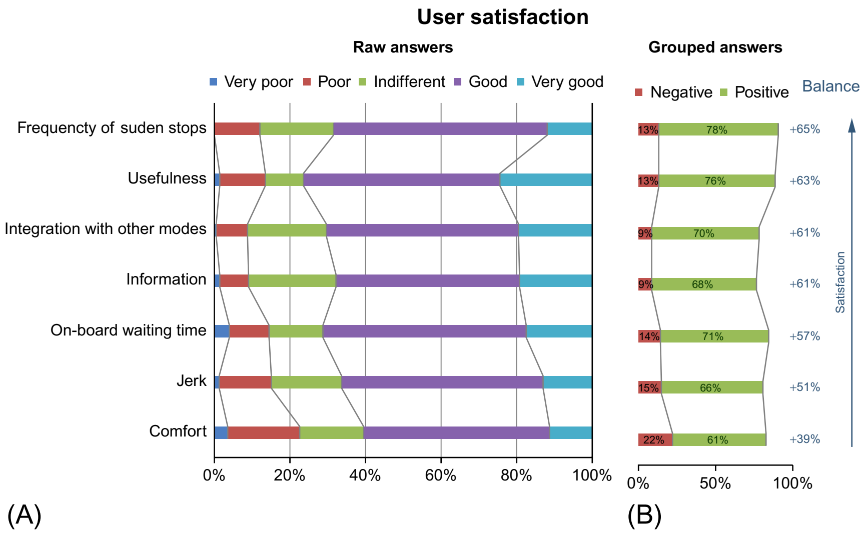

Fig. 3.7 ARTS user satisfaction, (A) raw answers and (B) grouped answers.

- Comfort: global comfort, frequency of sudden stops, and jerk
- Information

Fig. 3.7A shows the answers of participants on the different evaluated criteria concerning user satisfaction. Fig. 3.7B shows the responses grouped in the following categories: negative (poor and very poor) and positive (good and very good). The last column on the figure shows the overall balance per criteria that was obtained by the sum of the percentages of the positive category minus the percentage of the negative.

The comfort of the system was rated the least positive with an overall balance of +39%, and it will certainly require improvement for future experiments. The frequency of sudden stops and the usefulness of the system were rated the most positive with overall balances of +65% and +63%, respectively. The criteria of jerkiness and on-board waiting time obtained overall balances of +51% and +57%, respectively, that might require attention for future experiments.

The overall result on user satisfaction was positive with all considered criteria and between 60% and 80% of respondents declaring a positive opinion on them. The average overall balance for all criteria was +56%.

3.2.3.2.3 ARTS Use in the Future

The users were asked if they will use this ARTS service if it will be implemented on a permanent basis. For this question, the options were as follows:

- No
- Yes, without or with a member of the operating company's staff
- Yes, only if a member of the operating company's staff is on board

Ninety-three percent of respondents were willing to travel on a similar system in the future. Approximately 58% of respondents would like to use it without a human operator on board. This category was characterised in most of the situations by the users between 34 and 54 years old and usually with the employee professional status.

However, 35% of the sample would only use it if there would be a human operator on board. This category was represented by the users aged more than 64 years old. For the future adoption of the system, it is critical to understand the concerns of this category (elderly) and to consequently determine how they could be addressed (transport and environmental data on ARTS performances).

3.2.4 LESSONS LEARNT

Some lessons can be drawn from La Rochelle's demonstration:

- It is important to limit the ambition of the route and to be aware of the limits of the system prior to the implementation. The vehicles tested (RobuCity and Robosoft) were R&D vehicles, not yet optimised for public transportation purposes. The reality is very often more demanding than the plans. In order to tackle this issue, a very reactive local team (from the setup phase) is crucial taking into account the 'real urban conditions' of a city and to support changes in plans.

  Operators on-board vehicles are a key contact point for users. Their presence—like grooms in the lifts in another century—seems useful if not necessary in the short term, not only for safety reasons but also to address social issues and inform passengers.
- La Rochelle paid much attention on information and communication, the first aspects prior to the demonstration. There was a wide stakeholder's consultation, involving a lot of local actors impacted at various degrees by the demo. Attention was paid to keep the public informed on the progress of demonstration preparation and implementation, especially in situations of unexpected delay.
- A clear successful reason of the success of La Rochelle demonstration was the awareness-raising actions it carried out. We learnt that it was essential to engage the citizens from the youngest age to the elderly. An action like the special edition of 'Le Petit Quotidien' was of benefit not only for the pupils but also for all, as it generated exchanges between generations, discussions (even basic) on a topic often considered as 'reserved for experts only'.

- The development of ICT services around the ARTS would benefit to the service. It was not possible to implement such services within CityMobil2 experimentation, but it has to be developed for future ones.

3.2.5 CONCLUSIONS AND FUTURE PLANS IN THE CITY

CityMobil2 large-scale demonstration carried out in La Rochelle was definitely a success. Here are some facts:

- A total of nearly 15,000 passenger trips (14,661 trips) have been done.
- Even regular users were registered.
- The surveys that were carried out show a satisfaction of the users, a warm welcome of the population. The care taken in the stakeholder's involvement, the awareness-raising actions and the communication campaigns were crucial for reaching this level of interest.
- There was a good confidence in the system and a good cohabitation between the automated vehicles and the other road users, notably the most vulnerable ones, that is, pedestrians and cyclists.
- La Rochelle's demonstration was a significant step towards an evolution of the legislation. Thanks to the dialogue (long but always useful) with the national authorities, we believe that CityMobil2 has paved the way for a creation of a legal framework for automated road transport systems.
- However, we are aware that these exchanges need to continue and the communication between the different levels of authorities needs to be improved.
- The legislation should focus not only on demonstrations but also on long-term and even permanent automated road transport services.

However, the partners did not fully reach the ambitious goals we considered initially and had targeted in terms of mobility service.

The combination of technical and practical issues had indeed an impact: our demo route had to be revised and did not serve fully the mobility need we anticipated—notably not serving the main train station. But the technical teams and the coordinator adopted on this a realistic and flexible approach. As the reality is always more demanding than the plans we draft, we took well into account the constraints related to the implementation of such services.

The deployment of ARTS could have been not enough accompanied by surrounding services in order to make ARTS more attractive and

user-friendly. We have to take this into account in the future plans we would like to consider. It is not only about automated vehicles but also about automated transport services.

The speed of the vehicle was often considered as too slow, and the frequency between two vehicles is too low. On the one hand, the users were confident in the vehicles both on and off board because of the slow speed. On the other hand, as a mobility service, users tended to think that the commercial speed of the vehicles should be raised.

We should now consider a long-term deployment of ARTS in La Rochelle responding to a real and identified mobility need.

La Rochelle partners would like to go further in the introduction of automated transport systems, if possible in the short term. La Rochelle would aim at providing a public transport service. Such an implementation can be achieved only through a strong and continuous dialogue, collaboration and engagement off all stakeholders: experts, manufacturers, authorities, insurance companies.

The objective would be to offer an efficient environment-friendly transport service that would connect main mobility attractors and generators such as parking and the future interchange hub at the central train station.

Such a route would complete (and even for some legs compensate) the conventional public transport network.

Automated systems offer the possibility to combine flexibility and efficiency in the public transport. With this flexibility, new approaches regarding the operation of the systems arise in order to have an adapted and differentiated transport offer during the peak and the off-peak hours. There would be a continuous adaptation of the automated transport in order to meet the demand: when needed, additional vehicles would be introduced in the service, following the demand that would be calculated in real time. The operation of the system could be effective on a wider time frame/larger schedules. Taking into account the specificity of La Rochelle (historical) city centre, implementing an automated shuttle service would be more adapted and efficient (frequency) than conventional buses.

Furthermore, operating a shuttle service is not very appreciated by the shuttle drivers themselves. On short routes, the operation is much repetitive. Therefore, operated for these specific services, an automated system would contribute to improve the social conditions whilst providing more flexibility to the service.

Our ambition would be to implement an efficient transport service: combining reasonable average commercial speed (e.g. 15 km/h) with the necessary safety requirements.

Our objective is that the future road transport services are not taken as a simple attraction. They will address a need and ensure a mobility service both efficient and flexible. They will in our mind be an efficient, flexible supplement that would encourage us to use public transport.

REFERENCE

[1] M. McDonald, P. Delle Site, D. Stam, M.V. Salucci, CityMobil2 evaluation framework, in: Implementing Automated Road Transport Systems in Urban Settings, Elsevier, 2017.

CHAPTER 3.3

Evaluating ARTS in Trikala

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3.3.1 INTRODUCTION

Automation of road vehicles is expected to increase road safety traffic efficiency, so a lot of efforts are underway to develop autonomous vehicles and deploy them in real traffic conditions as described in Refs. [1–6].

Still, research about public attitudes towards such vehicles mainly consists of questionnaire surveys of a priori attitudes as described in Refs. [7–11], since autonomous vehicles are not yet fully accessible to the public. The CityMobil2 project, cofunded by the Seventh Framework Programme of the European Commission, organised long demonstrations of autonomous vehicles in European cities aiming to understand the factors that may impact on people's acceptance and usage of autonomous vehicles [12].

Within the framework of CityMobil2, the city of Trikala in Greece organised a 4-month demonstration of autonomous minibuses for passenger transport in the city centre. Trikala is populated by 81,355 inhabitants (data from 2011) and covers an area of 608.48 km^2. It is the main financial, commercial and operational centre of the prefecture and hosts several university departments. The city road network is of radial form spreading from the city centre, obstructed by a railway line and a river flowing through the city centre. Daily traffic in the city is on average 19,180 vehicles, with two peaks, at 08:15–09:00 and 14:00–15:00. There are on average 3500 public transport passengers per day. During peak hours, traffic consists of 66% private vehicles, 4% buses, 4% taxis, 9% trucks, 8% motorcycles and 9% bicycles. One of the main problems the city faces is the fact that there is no public transport connection of the historic 'Varoussi' district to the city commercial centre, which hosts the central bus terminal, commercial and recreational facilities and public administration and health establishments for the citizens. Public transport is not permitted in the Varoussi district, so this creates problems for last-mile travellers who live in this area and in the adjacent neighbourhoods. Considering its interest in innovative technologies in general, the Municipality of Trikala was keen to host the demonstration of autonomous minibuses for passenger transport. It was expected that this could serve last-mile transport in the city centre, serving areas

that are vital for the city's everyday function, namely, the historic old city, the local trade market, the central periodic open-air market, banks, public services and various points of interest for citizens and visitors, without adding pollution. Additionally, this demonstration would increase the city's visibility as 'digital' city with high ICT adoption rate and would attract visitors and investors.

A driverless vehicle may seem very distant to the average road user, creating concerns about its safety and reliability, and this could result in unwanted public reactions. For this reason, the demonstration in Trikala was carefully designed so as to guarantee maximum safety of all road users. Additionally, long preparatory information campaigns were planned and conducted to reassure citizens about their safety during the demonstrations.

This paper presents the design of the autonomous minibus route in the city of Trikala, the preparatory actions taken as regards adaptations to the road infrastructure, the organisational and legal measures and public awareness campaigns, the demonstration activities conducted and the findings as regards citizens' perceptions and acceptance after the demonstrations.

3.3.2 DEMONSTRATION DESIGN AND PREPARATORY ACTIONS

3.3.2.1 Route Design

Fig. 3.8 shows the 2.4km loop route; it was designed to be served by the six autonomous minibuses with a capacity of 11 passengers (6 seated, 4 standing and 1 wheelchair user) in the city centre, crossing the river at two locations and aiming to attract last-mile travellers and serve inhabitants of the Varoussi area. The route connected key points including the central bus terminal, the central square and bridge, the commercial city centre and buildings of public services (mainly health-related).

The route crossed pedestrian zones, bicycle paths, normal city streets, including streets with heavy traffic during peak hours, and 34 intersections. It was decided that in case of intersections, the minibuses would have priority, signalled through traffic signs or smart traffic lights. The minibuses should realise seven right and four left 90 degree turns. The characteristics of the route, namely, total time, distance travelled, number of stops, mean waiting time per stop and mean travel time, are presented in Table 3.5.

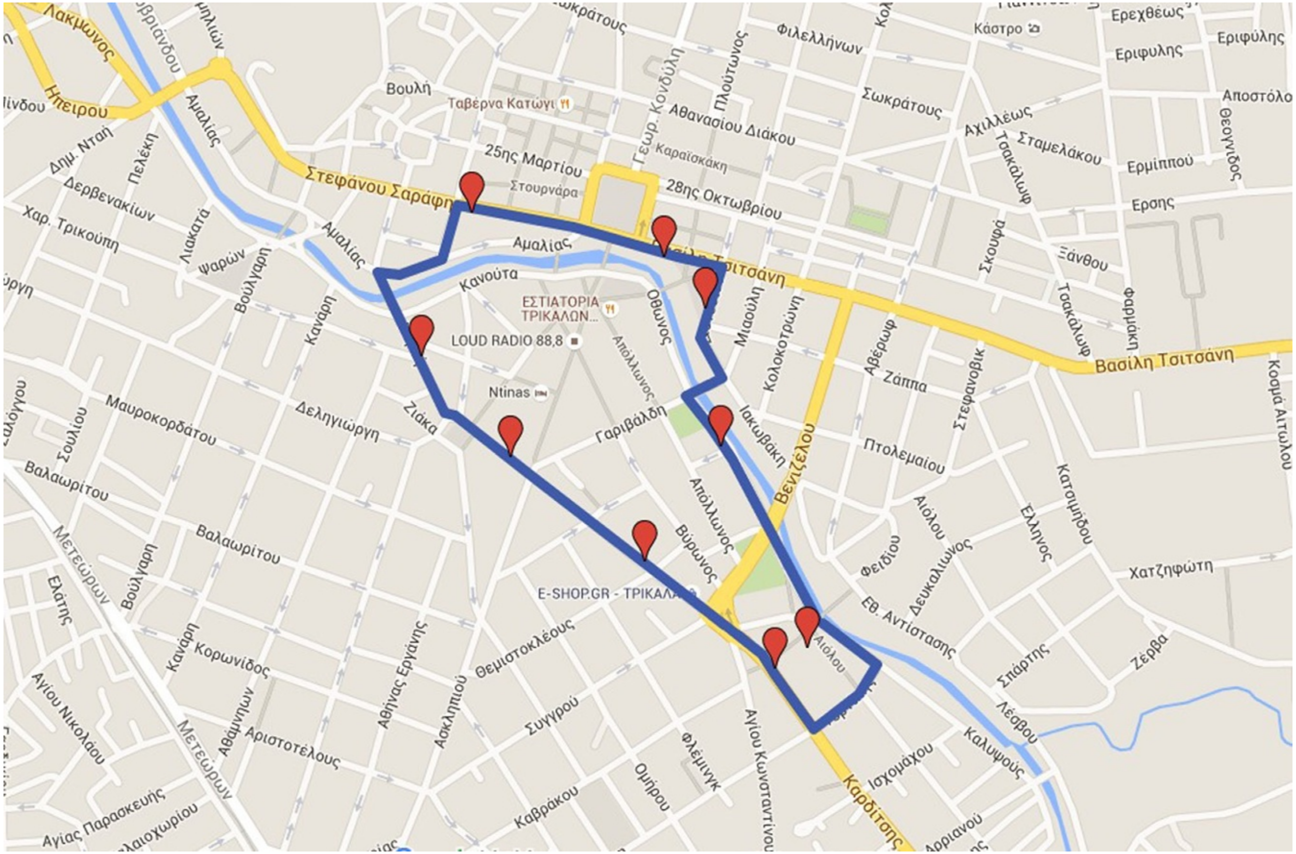

Fig. 3.8 Route of the autonomous minibus in Trikala.

Table 3.5 Characteristics of the autonomous minibus route in Trikala

Total trip time (min)	Trip length (km)	Number of stops	Mean time per stop (min)	Mean moving time per trip (min)
29	2.4	9	1	20

3.3.2.2 Legal Measures

In Article 48 (regulating issues relevant to the traffic code) of the Law 4313 / 2014, paragraph 4 allows the circulation of urban buses without a driver on board only for research purposes in the framework of a pilot, after a decision by the Municipal Authority and the approval by the local traffic police. Paragraph 5 of the same article requires that the driverless urban buses should be equipped with mechanisms and systems that should ensure that its movement, braking and stopping behaviour are similar to that of a vehicle driven by a human. Paragraph 6 requires the video monitoring of the buses and of the road scene from a control centre, via cameras on board the vehicle and on predetermined points along the route, to enable the bus immobilisation if needed. Paragraph 7 requires that the person responsible for monitoring the buses in the control centre should possess an appropriate driving licence and will be responsible for its immobilisation like the vehicle driver. A ministerial decree by the Minister of Transport further defined the necessary terms and conditions. This decree defines a driverless vehicle as 'a transportation means that moves on a specified route or on dedicated lanes and whose movement is regulated by a person responsible for monitoring the movement, who is not in the vehicle'. The decree also defines that the person responsible for monitoring the movement is 'accounted as the vehicle driver according to the traffic code'.

The decree permits the circulation on a bus lane of urban buses without a driver on board, exceptionally to paragraph 1 of Article 13 of the traffic code, only for research purposes, after a decision by the municipal board and the agreement by the traffic police authorities, for a specific time period and on a specific route, determined in accordance to a traffic study.

3.3.2.3 Infrastructural Adjustments

A speed limit of 30 km/h was imposed on all road segments along the route. A dedicated bus lane of 2.5 m in width was constructed, marked with different colouring or texture of the road surface, cats' eyes and traffic segregators. Cats' eyes were used at all intersections to delineate the bus route, and smart traffic lights were installed to give priority to

Fig. 3.9 Dedicated lane delineation and traffic signs.

the minibuses over other vehicles. Nine new bus stops, specifically for the minibuses, were created along the route. Additional specific adaptations to the traffic infrastructure were implemented at specific points along the route, as necessary. Informatory signs were placed at several points along the route to inform drivers and citizens about the demonstration and the specific restrictions imposed. Fig. 3.9 shows the ARTS lane and dedicated traffic sign at stops.

All on-street parking places along the route were removed, to facilitate the minibus circulation. Wi-Fi access points and fibre optic network were installed along the route.

A central depot for the minibus parking and charging and a control centre were built and put into operation. The control centre enabled the remote monitoring of the minibuses by specifically trained operators who could communicate with the vehicle and intervene in case of an emergency. Four operators have been trained by authorised personnel of the minibus manufacturer, following a specific training protocol, so that they were able to monitor the minibuses and intervene in case of any issue, as needed. Each operator had to complete at least 40 h of operation before being certified (Fig. 3.10).

3.3.2.4 Preparing the Public for the Demonstration

Since the presence of an autonomous minibus in real traffic conditions was very innovative, dedicated awareness-raising campaigns started long before the demonstrations. The main aim was to inform the citizens about the planned demonstration and the expected benefits to the city, to motivate them to use the autonomous minibuses and to ensure them about their own safety. A secondary aim was to inform the citizens in advance about the necessary traffic changes, such as new traffic restrictions and the creation of a dedicated bus lane, so that they would be better prepared as regards

Fig. 3.10 Operator in the control room.

their everyday activities, for example, for parking or urban goods deliveries. Special road signs and flags containing the project logo and motto were placed along the route to prohibit parking and to indicate the route that would be used by the minibus in the demonstration period.

Representatives from the CityMobil2 working team and from the Trikala municipal authority and the mayor personally widely communicated the demonstration objectives and the added value of the autonomous minibus demonstration for the city, namely, the expected benefits from the implementation of the infrastructure and the increased attractiveness of the city for tourists and others. Various channels were used to inform the citizens, including local and national TV channels, newspapers and internet news sites. Flyers and posters were distributed during the preparatory and demonstration phases to citizens and shop owners, to inform them on the scope of the demonstration, the planned route and the implementation phases.

Field tests with the minibuses started in September 2015. This initial testing period served as an additional opportunity to promote the autonomous minibuses to the local community and was widely covered by the local and national media.

An official opening event took place on 10 November 2015. The Trikala mayor and representatives from the University of Rome, the Greek Ministry of Infrastructure, the Institute of Communication and Computer Systems and major stakeholders were invited to speak about the project. In parallel, a conference was organised with presentations on the required technologies, systems and solutions for automated vehicles and about mobility and automated mobility. All the stakeholders and speakers were given the opportunity for a first official tour aboard the automated vehicles. This event was

widely covered by not only many local and national but also international media; more than 175 references were made at a national and international level, in newspapers and magazines, and 20 video reportages were broadcast in international and national channels.

3.3.3 THE DEMONSTRATION

The demonstration started on 10 November 2015 and lasted until 29 February 2016. All six vehicles are operated on the planned route; Fig. 3.11 shows a vehicle in operation. Apart from the operator in the control centre, there was an operator on board the minibuses, who mingled with the rest passengers, so as to minimise the potential for his/her presence to be detected. The role of this operator was to supervise and intervene, only in case of a deviation or malfunction of the system.

The minibuses completed 1490 trips during the demonstration period. The minibuses covered 4030 km and transported 12,138 passengers (up to 700 daily passengers as shown in Fig. 3.12), with an average of 8.15 passengers per trip (Table 3.6).

3.3.3.1 Citizens' Perceptions

The ARTS operation in the demonstrations has been evaluated on the basis of the CityMobil2 framework, reported in Ref. [13].

During January and February 2016, a questionnaire survey among citizens was conducted. Questionnaires were randomly sent via a prepaid mail service to

Fig. 3.11 The autonomous minibus in operation in Trikala.

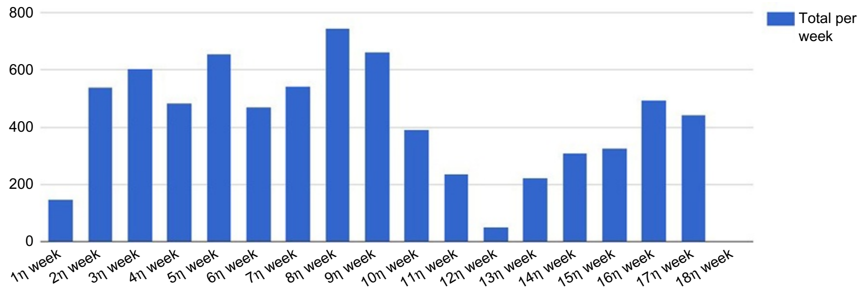

Fig. 3.12 Passengers per week (from 1 November 2015 to 26 February 2016), Christmas being the 8th week.

Table 3.6 Passengers during the demonstration

Minibuses	Total passengers	Total trips	Passengers per trip	Total km covered
6	12,138	1490	8.15	4030

citizens in urban and suburban areas of Trikala. Six hundred one questionnaires were completed, by 290 men and 311 women. Five hundred fifty-five of them were aware, and 46 were not aware about the autonomous minibuses before participating in the survey. Their responses as regards frequency of using the autonomous minibuses are shown in Table 3.7. Forty-six people who responded that they were not aware about the autonomous minibuses before participating in the survey also responded that they had never used them. Of the 555 who were aware, 343 responded that they had never used the minibuses, 100 responded that they had used them once, 94 that they had used them two to four times and 18 that they had used the buses more than five times.

The mean age of those who were aware but never used the minibuses was 39.4 years, whilst the mean age of those who used them was 36.5. The age distribution of aware respondents is shown in Table 3.8. The chi-square test of independence revealed a significant relation between age and usage

Table 3.7 Usage of the autonomous minibuses among respondents

	Never	Once	Two to four times	>5 times
Not aware about the autonomous minibuses	46			
Aware about the autonomous minibuses	343	100	94	18

Table 3.8 Age distribution of aware respondents (% responses)

	Aware but never used ($N=336$)	**Aware and used ($N=207$)**
< 18	11.31%	5.80%
18–24	10.12%	20.77%
25–34	19.94%	20.29%
35–44	20.54%	24.15%
45–54	20.54%	20.77%
55–64	12.20%	7.73%
65–74	5.06%	0.48%
> 74	0.30%	0.00%

of the minibuses among aware respondents. More people 18–24 years old used the minibuses than expected, whilst more people over 55 years than expected never used the buses $\chi^2(6, N=543)=17.2, P<.01$.

The educational level of aware respondents is shown in Table 3.9. The chi-square test of independence did not reveal a significant relation between educational level and usage of the minibuses among aware respondents.

The main transport means that the aware respondents usually use for trips to work, education or other everyday activities are shown in Table 3.10. The chi-square test of independence did not reveal a significant relation between habitually used transport means and usage of the minibuses among aware respondents.

The type of area in which the residence of respondents is located is shown in Table 3.11. The chi-square test of independence did not reveal a significant relation between the location of residence and usage of the minibuses among aware respondents.

The respondents' perceptions about the safety of autonomous vehicles compared with conventional vehicles are shown in Table 3.12. Comparing between respondents who were not aware and those who were aware but never used the minibuses, the chi-square test of independence revealed a significant relation between awareness about the minibuses and perceptions about the safety of autonomous vehicles $\chi^2(3, N=389)=22.9, P=0$. Respondents who were not aware responded more often that autonomous

Table 3.9 Educational level of aware respondents (% responses)

	Aware but never used ($N=325$)	**Aware and used ($N=206$)**
Secondary school	42.5%	35.4%
College	8.9%	11.7%
University/technical university	48.6%	52.9%

Table 3.10 Main usual transport means for everyday activities by aware respondents (% responses)

	Aware but never used ($N=335$)	Aware and used ($N=209$)
Driver	59.7% (mean age 46.3 years)	54.6% (mean age 41.7 years)
Bus	22.4% (mean age 28.5 years)	29.2% (mean age 30 years)
Walking	8.7%	7.2%
Motorcycling	6.9%	5.7%
Cycling	1.4%	1.9%
Car passenger	0.9%	1.4%

Table 3.11 Place of residence of aware respondents

	Aware but never used ($N=343$)	Aware and used ($N=212$)
City centre	28.6%	32.6%
Suburban	29.5%	28.8%
Other urban	30.3%	32.5%
Rural	11.6%	6.1%

Table 3.12 Respondents' perceptions about the safety of autonomous vehicles

	Aware but never used ($N=343$)	Aware and used ($N=212$)	Not aware ($N=46$)
Safer than	20.4%	32.1%	10.9%
As safe as	42.6%	54.2%	15.2%
Less safe than	37.0%	13.7%	73.9%

vehicles are less safe compared with conventional vehicles than aware respondents (73.9% vs. 37.0%). Among aware respondents, the chi-square test of independence also revealed a significant relation between the usage of the minibuses and their perceptions about the safety of autonomous vehicles $\chi^2(3, N=555)=36.4$, $P=0$. Aware respondents who never used the autonomous minibuses responded more often that an autonomous vehicle would be less safe than a manually driven one, 37% versus only 13.7% of those who used them. Respondents who used the autonomous minibuses responded more often that an autonomous vehicle would be safer than (32.1% vs. 20.4%) or as safe as a manually driven one (54.2% vs. 42.6%) than those who never used them although they are aware.

The respondents' willingness to use an autonomous vehicle, if it was available in the market, is shown in Table 3.13. Comparing between respondents who were not aware and those who were aware but

Table 3.13 Respondents' willingness to use an autonomous vehicle

	Aware but never used ($N = 3383$)	Aware and used ($N = 207$)	Not aware ($N = 43$)
Would buy one	38.8%	42.4%	11.6%
Would use one	34.3%	46.5%	7.0%
Would not use	26.9%	11.1%	81.4%

never used the minibuses, the chi-square test of independence revealed a significant relation between awareness about the minibuses and respondents' willingness to use an autonomous vehicle in the future $\chi^2(3, N = 381) = 51.2$, $P = 0$. Respondents who were not aware responded more often that they would not use an autonomous vehicle compared with those who were aware although they did not use it (81.4% vs. 26.9%) and less often that they would buy or use one. Among aware respondents, the chi-square test of independence also revealed a significant relation between the usage of the minibuses and willingness to use an autonomous vehicle in the future $\chi^2(3, N = 545) = 20.6$, $P = 0$. Aware respondents who never used the autonomous minibuses responded more often that they would not use an autonomous vehicle, 26.9% versus only 11.1% of those who used them. Aware respondents who used the autonomous minibuses responded more often that they would buy (42.4% vs. 38.8%) or use an autonomous vehicle (46.5% vs. 34.3%) than aware respondents who never used them.

3.3.4 DISCUSSION AND LESSONS LEARNT

Trikala was one of the European cities selected within the CityMobil2 project to organise large-scale demonstrations of autonomous vehicles in real traffic. The aim was to collect field data and understand the factors that may impact on people's acceptance and usage of autonomous vehicles after direct experience with them.

The findings indicate that age was a factor related to the usage of the autonomous minibuses, people 18–24 years old used the minibuses more often, whilst people over 55 years less often. This may be an indication that willingness to experience new transport technology reduces with age, but it may also indicate that elder people are less eager to use public transport or to change their habitual means of transport. The latter is supported by the mean age of respondents. Indeed, the mean age of habitual drivers who never used the minibus was higher (46.3 years) than of those who used it

(41.7 years), possibly meaning that elder respondents tended to commute via private car and were more reluctant to shift to a bus, including the autonomous minibus.

No relation between educational level or habitual transport means and usage of the minibuses was found in this survey. Similarly, no relation between residential location and usage of the minibuses was found in this survey, which may indicate that the minibuses were used by both last-mile travellers and citizens of the city centre.

The findings of this survey indicate that **awareness about the demonstrated minibuses was accompanied by perceptions of higher safety** of autonomous vehicles and by **higher willingness to use** autonomous vehicles in the future. In more detail, respondents who were not aware about the minibuses responded more often that autonomous vehicles are less safe compared with conventional vehicles than respondents who did not use the buses although they are aware about them (73.9% vs. 37.0%). They also responded more often that they would not use an autonomous vehicle in the future (81.4% vs. 26.9%). Although the lack of awareness could have been due to limited usage of information, media and technology by some people, for example, people who do not regularly watch television or hear radio or use the internet, these findings are an indication that direct experience with autonomous vehicles in real traffic may alleviate people's concerns and increase their trust and acceptance.

Respondents **who used** the autonomous minibuses responded more often that autonomous vehicles **would be safer** (32.1% vs. 20.4%) or as safe as a manually driven vehicle (54.2% vs. 42.6%) than aware respondents who did not use them. They also responded more often that they would buy or use an autonomous vehicle in the future (42.4% vs. 38.8% and 46.5% vs. 34.3%, respectively). These findings may indicate that **the usage of the autonomous minibuses led to perceptions about higher safety of autonomous vehicle and increased acceptance, as indicated by willingness to buy or use**. Although this may be due to different a priori perceptions among respondents, it may also indicate that direct experience with autonomous vehicles is a means to reduce psychological distance and thus increase their acceptance by users. If this is the case, more large-scale demonstrations of autonomous vehicles in real conditions should be organised, to verify these findings. Future studies should focus on whether a priori perceptions shape level of usage or whether usage may reshape a priori perceptions.

Finally, there were several useful lessons learned from the demonstration in Trikala that could be useful in future demonstrations of autonomous vehicles. It is essential to gain public acceptance and understanding before the demonstrations, especially from people living close to the affected area. Therefore, the informatory campaigns to the public should start long before the actual demonstration, to prepare and inform the public about the changes in infrastructure and traffic environment, like removal of parking places and traffic restrictions. The bus lane should be very clearly designated, and road users should get accustomed to the idea soon, to avoid obstructing the lane and thus the bus movement. The presence of an operator on board proved to be useful, so as to quickly cope with some limitations of the system, for example, obstacles in blind spots, illegal parking on the dedicated bus lane or in case of rainy weather. Thus, a human operator on board may be important at least for an initial period. It has proven to be very beneficial, to combine high innovation with tradition and tourism. The Trikala team attempted to connect the acute technological innovation of autonomous vehicles with tradition, naming each minibus after a famous local singer and playing his/her music via the bus speakers during the routes. The citizens and the numerous city visitors during Christmas really welcome this idea. Additionally, all the minibus stops were located close to major tourist spots of the city.

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CHAPTER 3.4

Evaluating ARTS in Lausanne

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3.4.1 INTRODUCTION

The ARTS demonstration in Lausanne was undertaken in the campus of Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland. Indeed, EPFL has been working since the 1990s on innovative public transport projects, the most well known of which are La Serpentine and Swissmetro. The first one was a disruptive project for the city of Lausanne with a fully autonomous shuttle, driven by a power supply by coils inserted in the ground with a contactless transmission of energy and at the same time serve as a guideline for the vehicle. Whilst all the work was completed on the demonstration line on the lake shore, the Federal Transport Office refused permission to operate, putting an abrupt end to the experiment. It is this historical trauma that EPFL has tried to cure with new attempts in the framework of European projects, with success, thanks to the determination of two partners of the Serpentine, who had become vice presidents of EPFL, Professor Francis-Luc Perret and Marcel Jufer.

EPFL has bought a first Navia shuttle in 2012 to best prepare the CityMobil projects. A first small demonstration of 3 weeks was successfully conducted in the summer of 2014 as part of the European CATS project with three Navia shuttles (see Fig. 3.13).

But it is in 2015 that the great demonstration of the CityMobil2 project has exploited the demonstration potential of these autonomous systems with six EasyMile models (Fig. 3.14).

3.4.2 OVERVIEW OF THE DEMONSTRATION

3.4.2.1 ARTS System Demonstrated

The demonstration on the campus of EPFL, Switzerland, started with an official inauguration on 17 April 2015 by the Swiss Federal President Ms. Simonetta Sommaruga and by the French President, Mr. François Hollande during his official visit to Switzerland.

In phase 1, four shuttles were involved to provide a service on a route of 1.5 km in length with six stops, operating from 7:45 a.m. to 10:00 p.m. from Monday to Friday, linking the 'traditional' public transport network on the southern and northern edges of the campus. The demonstration route can

Fig. 3.13 Navia vehicles in operation (CATS project).

Fig. 3.14 Navia vehicles in operation (CATS project).

be seen in Fig. 3.15. The demonstration of driverless vehicles came to an end in late August, and there were nearly 7000 people trialling the vehicles despite the summer holiday season. Fig. 3.16 shows the presentation event.

Thanks to the collaboration between the manufacturer EasyMile, the operator BestMile and the EPFL staff/students involved, the demonstration provided a high-quality service for the passengers. The main obstacles were due mostly to external factors such as badly parked vehicles, delivery and construction activities and meteorological conditions. One of the impacts

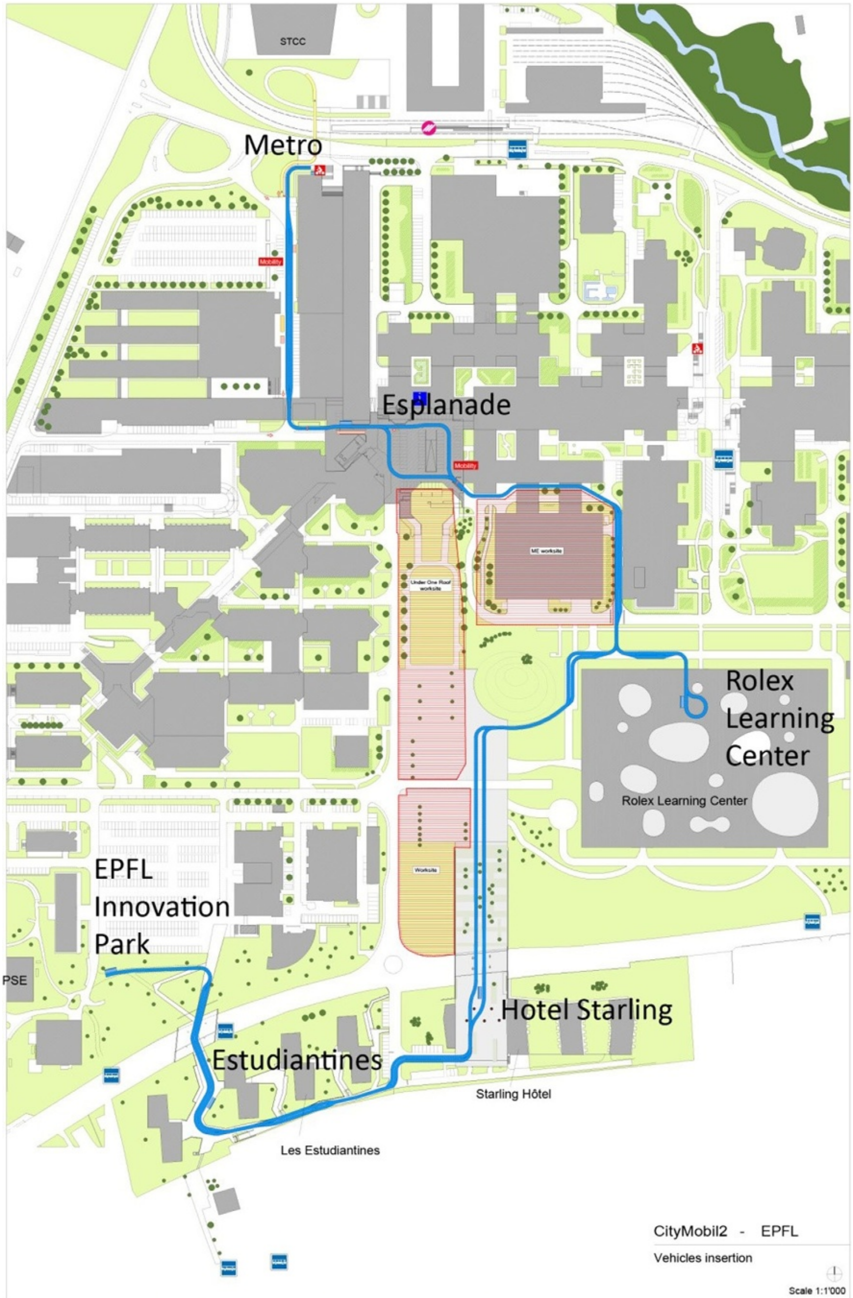

Fig. 3.15 Lausanne demonstration route.

Fig. 3.16 Lausanne presentation event.

of the construction activities was the interruption of a part of the shuttles itinerary at the end of the demonstration.

During the demonstration, great progress in terms of monitoring was achieved, thanks to BestMile that successfully implemented a remote fleet management system. Through this system, it was possible to monitor the entire fleet from a control centre and to give clear instructions to every shuttle of the fleet, about their speed, their itinerary, etc. This fleet management software made it possible to implement an 'on-request' app in July and August. Using this, passengers were able to call a shuttle with their smartphone and define their own destination. This was a successful implementation with approximately 1000 people using the mobile app.

Managing the delays in shuttle arrivals was one of the main challenges of the demonstration and has increased the cost of the project. These delivery delays also had a negative impact on the operation of the demonstration. Despite these problems, the reliability of the transport system has been demonstrated, with only minor incidents and no accidents.

3.4.3 SURVEYS

The ARTS operation in the demonstrations has been evaluated on the basis of the CityMobil2 framework, reported in Ref. [1].

Four different surveys were done during the demonstration:

- Ex post
- Ex post stated preferences of users
- Wider public
- Stakeholders

3.4.3.1 Ex Post Survey of Users

During ARTS demonstration, those people who rode ARTS vehicles were surveyed to assess their perceptions and satisfaction levels with the automated vehicle demonstrated in Lausanne. A total of 196 completed the questionnaires. The key results from the study can be summarised as follows:

- The respondents learned about the implementation of the ARTS service through various information sources. The most popular was the EPFL website, followed by word of mouth, flyers and chanced upon the system.
- The majority of the respondents (71%) used the ARTS services once only.
- Four-fifths of the users did not experience any technical incidents given the complexity of the system and the track.
- ARTS users were less satisfied with the journey times of ARTS vehicles. About two-thirds of the users rated 'waiting time' as very good or good. However, only two in five users rated 'in-vehicle time' as very good or good. One possible reason for such a low level of satisfaction was the very low speeds of the automated minibuses.
- ARTS users were less satisfied with the smoothness of ARTS vehicle movement. About half of the users rated seating availability, crowding level inside vehicle and clear view of outside as very good. However, less than a third gave the same rating regarding smoothness of vehicle movement (jerk-related).
- In general, user satisfaction levels of service and comfort were high. Over a half of the users rated usefulness, level of integration with other transport modes, level of service, comfort and information provision as either good or very good.

As a result, an extract of the main results of the survey is shown in Fig. 3.17.

The respondents were asked to consider the following aspects of public transport comfort and assign a score of 10 to the most important.

The respondents were asked to rate their level of satisfaction regarding comfort during their trip on the ARTS. Most of the factors were rated very good or good (Fig. 3.18).

3.4.3.2 Ex Post Stated Preference Questionnaire of Users

The objectives of the ex post stated preference (EPSP) survey carried out in Lausanne were as follows:

- To investigate users' relative preferences for automated road transport system (ARTS) versus a conventional one.

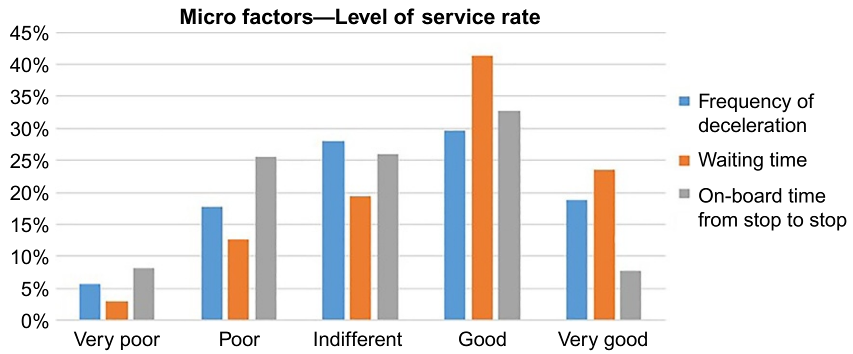

Fig. 3.17 How would you rate your satisfaction regarding the level of service?

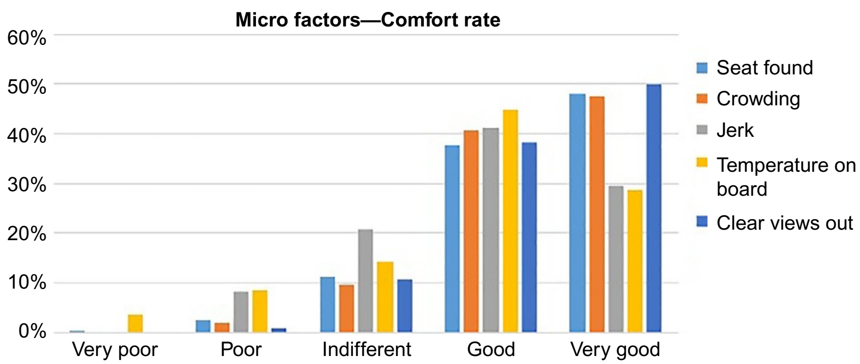

Fig. 3.18 How would you rate your satisfaction regarding comfort?

- To be able to assess attitudinal changes following user experience of ARTS by comparing the results with those of the ex ante survey. User preferences for ARTS were determined in an ex ante stated preference survey in all cities hosting a demonstration. Comparing the ex post and ex ante survey results enables an assessment to be made as to whether experience of the system and more information about it (thanks to the awareness-raising campaigns carried out in the cities hosting a demo) might have resulted in changes in user attitude towards the ARTS.
- To assess the ARTS users' perception of safety, security and emergency management as compared with a conventional system.
- To assess users' willingness to pay for the ARTS and their attitude towards the use of the ARTS system in the future.

The EPSP survey carried out in Lausanne was based on face-to-face interviews using a structured questionnaire. The number of respondents was 197.

3.4.3.2.1 Ranking of Micro-Factors

Key results found were as follows:

- Users appear to trust the automation capabilities of ARTS vehicles and feel safe inside them (Fig. 3.19).
- About one out of five users were willing to pay more for ARTS than the current PT fare if the demonstration service would be implemented on a permanent basis. But as many as four users out of five were willing to pay more if the ARTS system would provide a door-to-door service, with one out of four willing to pay more than 100 EUR on top of the current PT fare (Fig. 3.20).
- More than four out of five users thought that it is useful to implement the ARTS service on a permanent basis, but the majority of them thought that it would be better implemented on a different route (Fig. 3.21).
- The EPSP survey shows that users have a relatively higher preference for ARTS (ASC positive ex ante and ex post) regardless of whether or not they had experienced the system (Fig. 3.22).
- The impact on modal share of an extra fare applied to the ARTS service is significantly higher after experiencing the ARTS service, probably because of the low performances of the demonstration service.

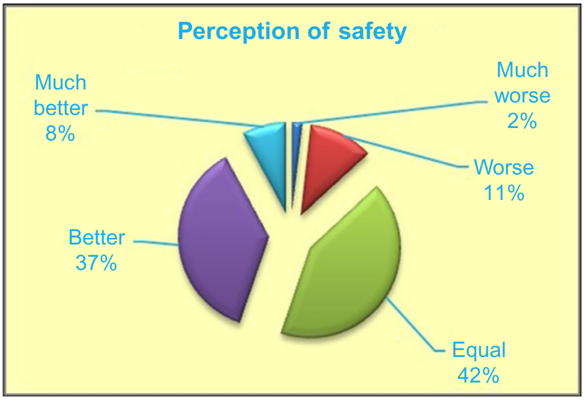

Fig. 3.19 Ex post SP users' perception of safety.

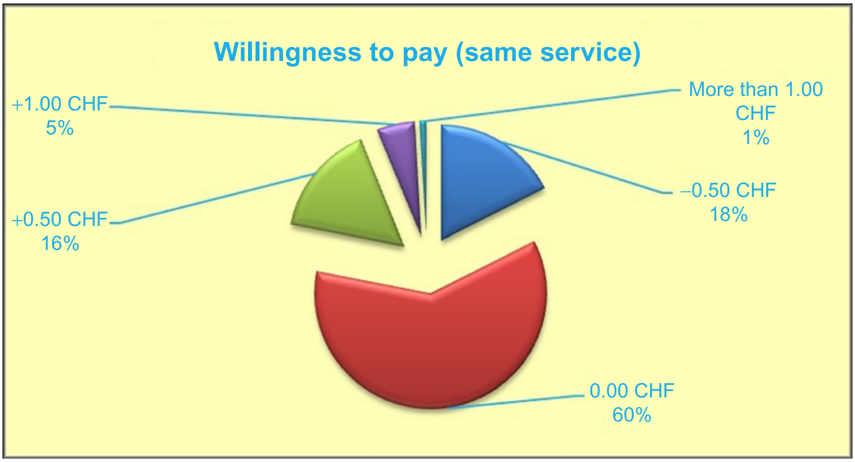

Fig. 3.20 Ex post SP willingness to pay for the same service.

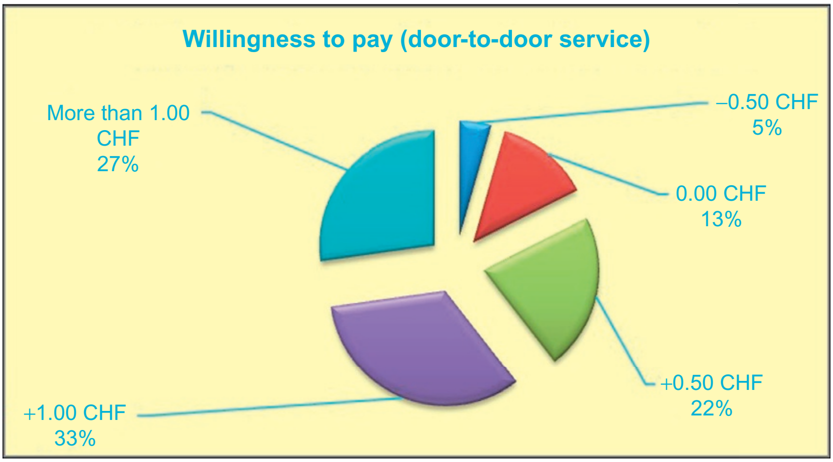

Fig. 3.21 Ex post SP willingness to pay for a door-to-door service.

3.4.3.2.2 Ranking of Macro-Factors by Importance

The respondents rated the level of your satisfaction for the above-mentioned aspects experienced using the ARTS service (Fig. 3.23). All the factors were mostly rated good.

3.4.3.3 A Wider Public Survey

This survey aimed to examine public opinion regarding automated vehicles in urban areas. A total of 586 people who were sampled from campus users of Lausanne Engineering School (EPFL) participated in the survey. The main findings can be summarised as follows:

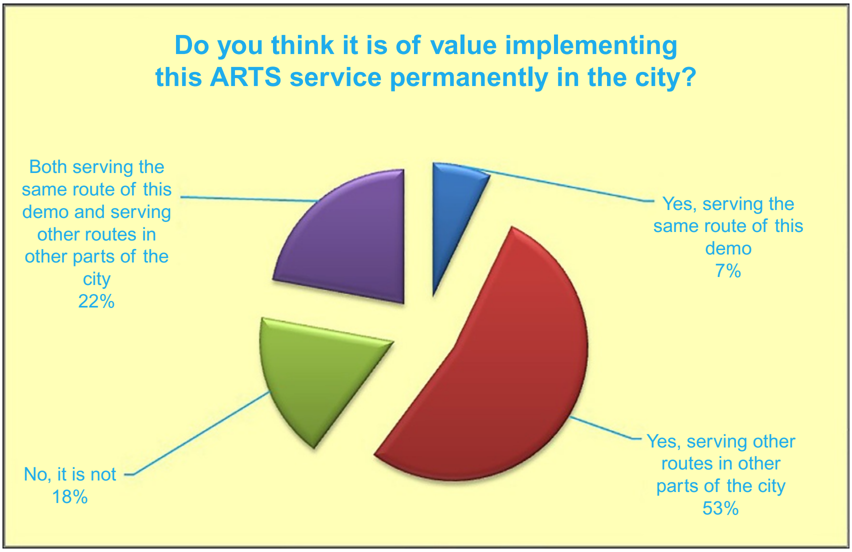

Fig. 3.22 Ex post SP users' attitude towards ARTS future use.

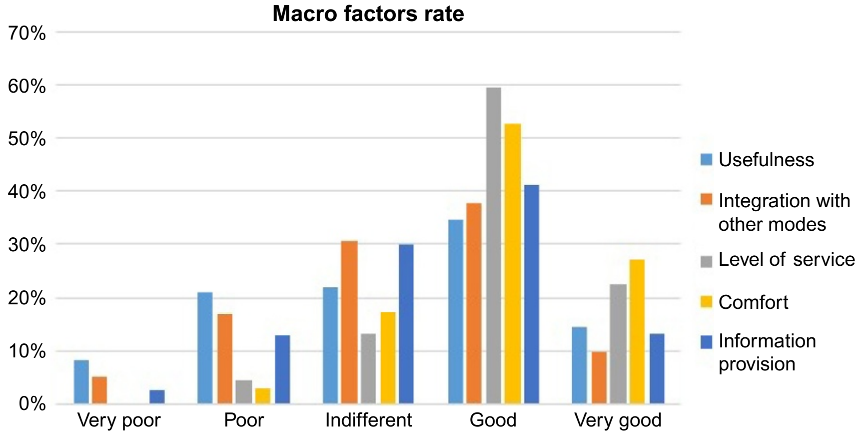

Fig. 3.23 How would you rate your satisfaction regarding macrofactors?

- Of the respondents, most (96%) had previously heard of automated vehicles, and about one-third had riding experience of the automated minibuses demonstrated in Lausanne. For the respondents, the most confident benefit was 'reduced energy consumptions' (43% answered 'very likely'), followed by 'reduced pollutant emissions' (39%) and 'reduced accidents' (38%) as shown in Fig. 3.24.
- A half of respondents think that automated vehicles are safer than human-driven vehicles, and 38% think that they are safe at same way (Fig. 3.25).

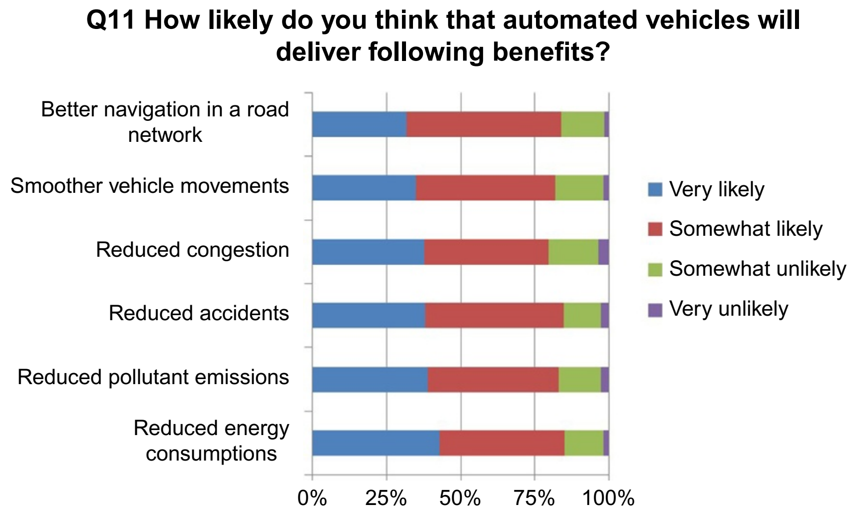

Fig. 3.24 Expected benefits.

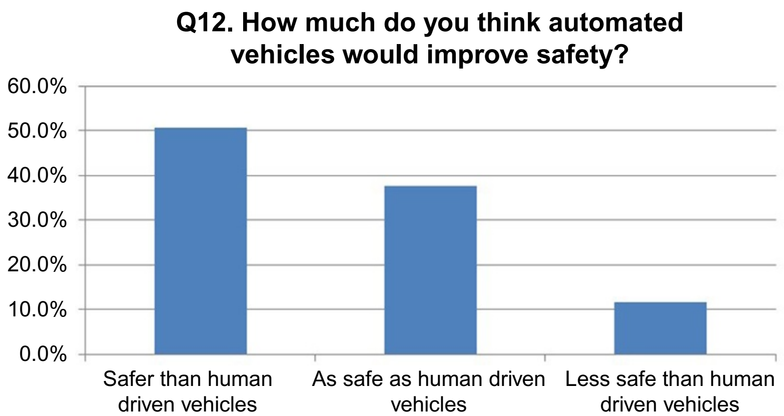

Fig. 3.25 Improving safety.

- For the automated minibuses demonstrated, the most supportive role was seen for it to complement public transport as feeders/distributors (Fig. 3.26).
- The most attractive benefit of automated buses was reduced fares with over a half of the respondents claiming it as very attractive (Fig. 3.27).
- Passenger security was one of the most concerned issues for automated buses, with nearly three quarters of the respondents being very concerned about night-time services (Fig. 3.28).

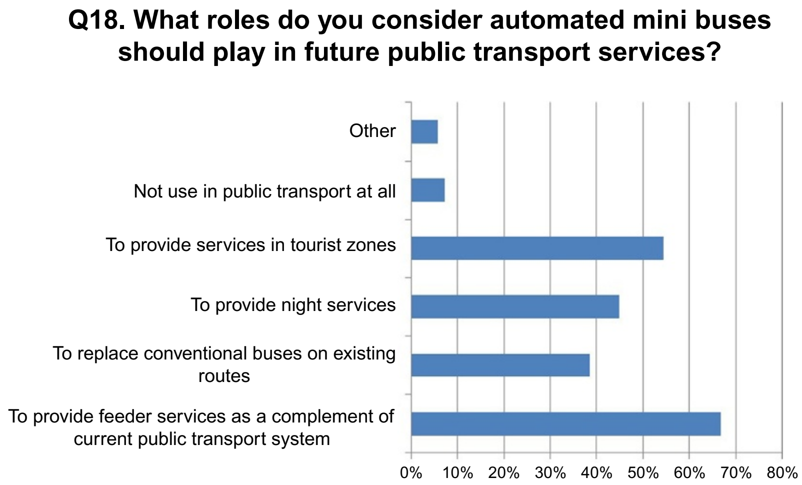

Fig. 3.26 Roles of the automated minibuses in urban transport.

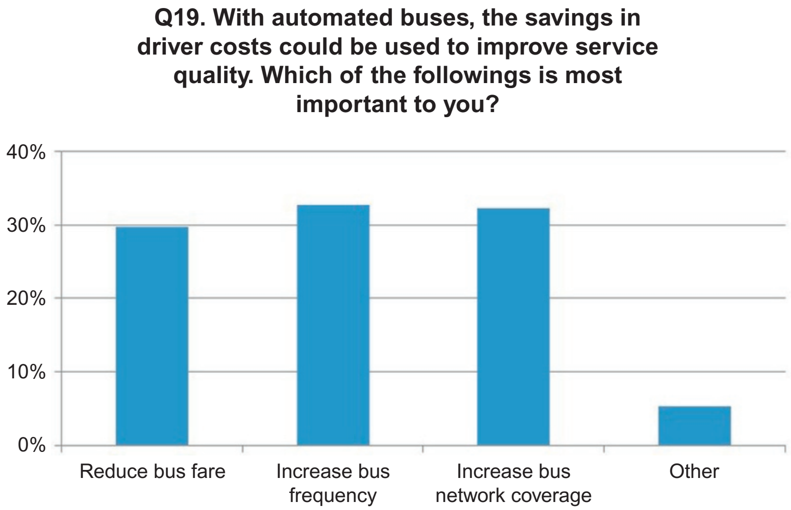

Fig. 3.27 Priorities of service quality improvements.

- Over two-thirds of the respondents (69%) stated that they would choose automated buses if both automated and conventional buses were available on the same route (Fig. 3.29).
- As shown in Fig. 3.30, more than 70% of the respondents (very attractive greater than 50% and moderately attractive about 20%) think that automated cars increase mobility of elderly and disabled and are safer due to elimination of human errors and reduce fuel consumption and emissions.

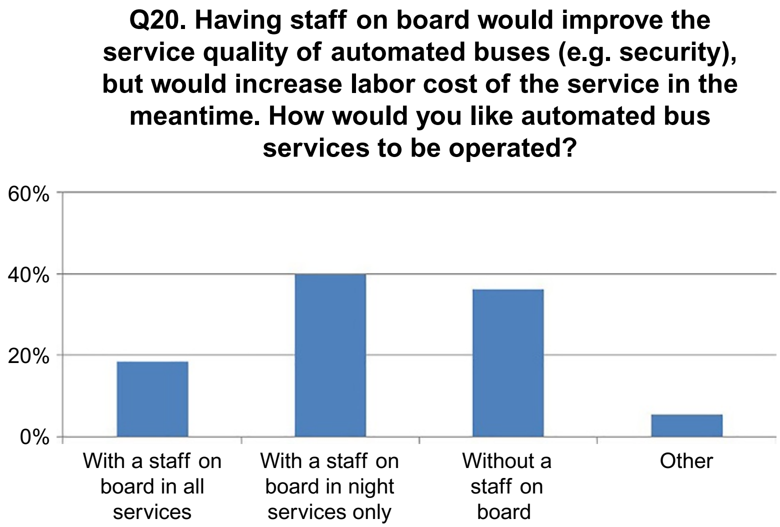

Fig. 3.28 Staff on board of automated buses.

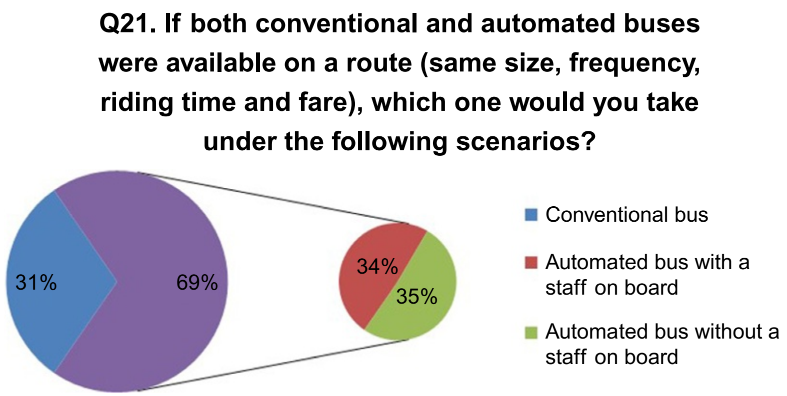

Fig. 3.29 Choice between automated and human-driven buses.

- Fig. 3.31 shows what people think about automated vehicle issues; about 50% of them are very concerned of these risks: vehicle security, disclosing location without their consent and system failures.
- Most respondents had positive views on to automated taxis. Of the benefits of automated taxis, reduced fares were the most attractive to the respondents (71% answered very attractive and 22% moderately attractive). Over a half of the respondents would consider using taxi service more if automated taxis become available.

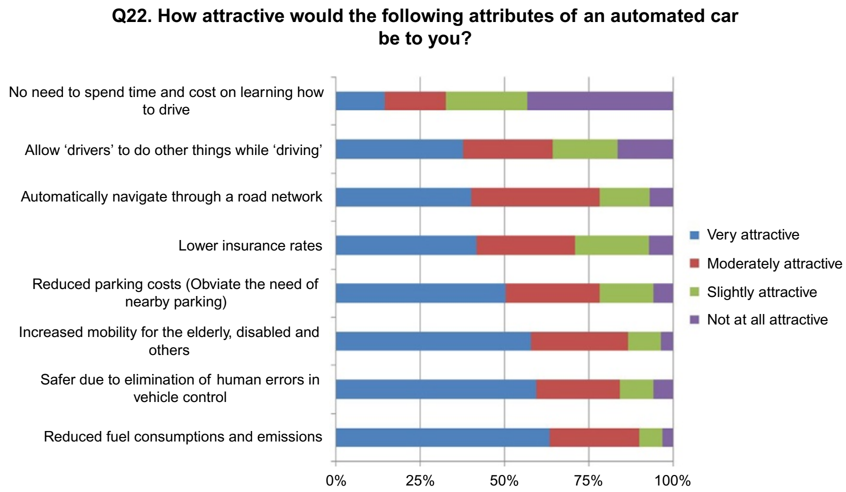

Fig. 3.30 Attractiveness of automated cars.

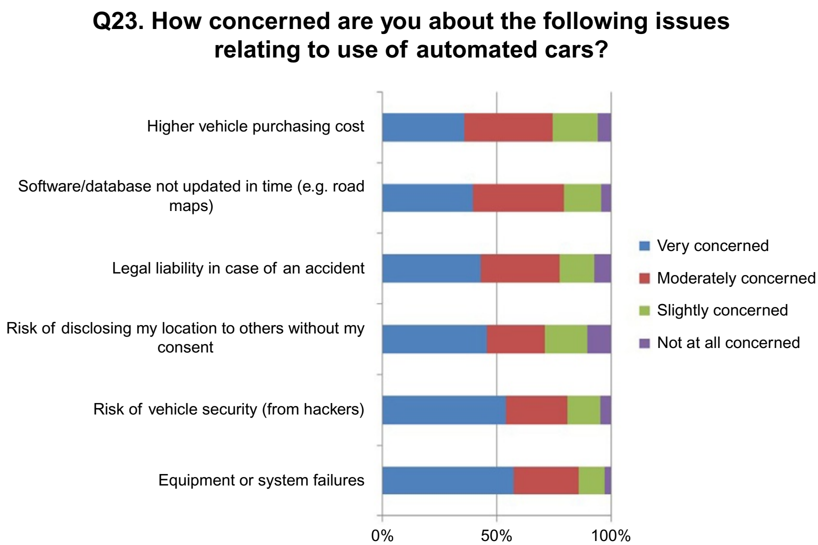

Fig. 3.31 Concerns to automated cars.

- Of the respondents, over a half (53%) stated that they would consider using taxis more if automated taxis become available.
- Regarding car-sharing and car-pooling services, implementation of automated cars was an attractive factor for the people surveyed. Regarding car-sharing services, as shown in Fig. 3.32, the most appealing benefit of

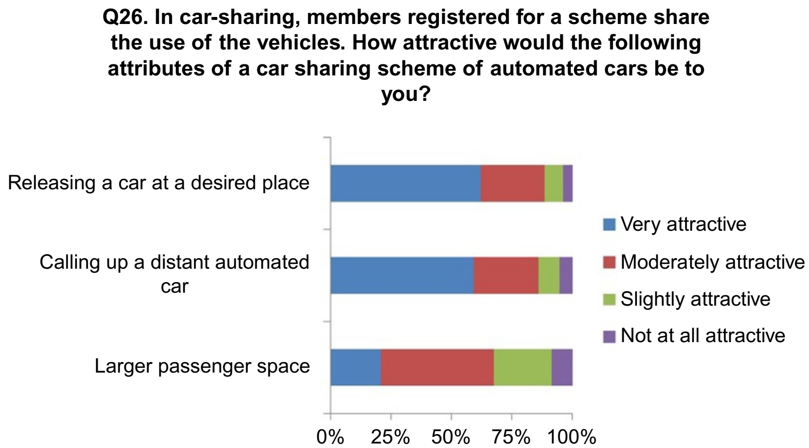

Fig. 3.32 Attractiveness of car sharing with automated vehicles.

automated cars was 'releasing a car at a desired place' (62% claiming it as very or moderately attractive); this was followed by 'calling up a remote automated car' (59%) and 'larger passenger space' (21%).

- Regarding carpooling, the most attractive benefit of automated cars was 'reduced fares' (55% answered 'very attractive'), followed by 'driverless' (37%) and 'larger passenger space' (26%).

3.4.3.3.1 Car Sharing

For car-sharing services, automated cars are expected to provide several advantages compared with conventional cars. These include larger passenger space, calling up remote cars and releasing cars at desired place. As shown in Fig. 3.32, most respondents were interested in each of the three new features brought by the automated cars (very attractive, moderately attractive or slightly attractive). Of the benefits, the most appealing one was 'releasing a car at a desired place' (62% answered 'very attractive'), followed by 'calling up a distant automated car' (59%) and 'larger passenger space' (20%).

At the question 'if automated cars become available on the market, would you like to use them?'(Fig. 3.33), 67% of the people answered 'yes', 48% of them would use an automated vehicle through a car-sharing/car-pooling service, and 19% of positive answers say that they will buy its own vehicle. The male respondents are lightly more (about 5%) interested to use automated vehicles (Fig. 3.34).

3.4.3.3.2 Education

Similar trends were found in the choice of using automated cars regardless of education levels received below or above bachelor's degrees (Fig. 3.35).

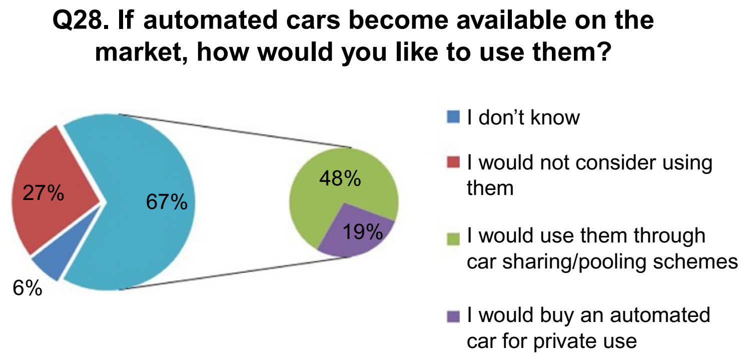

Fig. 3.33 Attitudes towards owning/sharing automated cars.

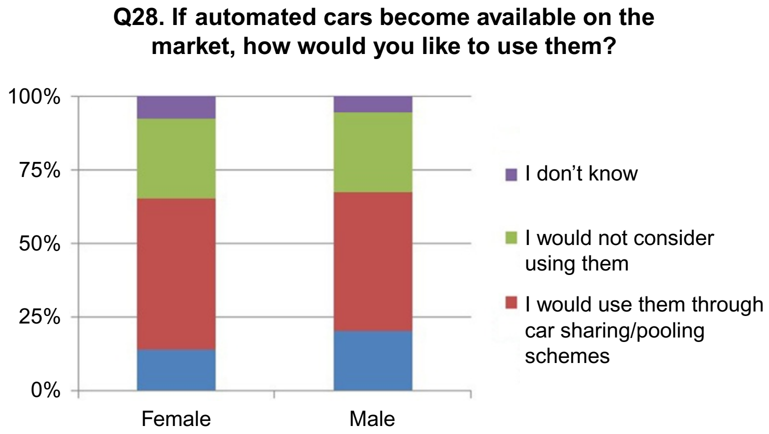

Fig. 3.34 Gender and attitudes towards owning/sharing automated cars.

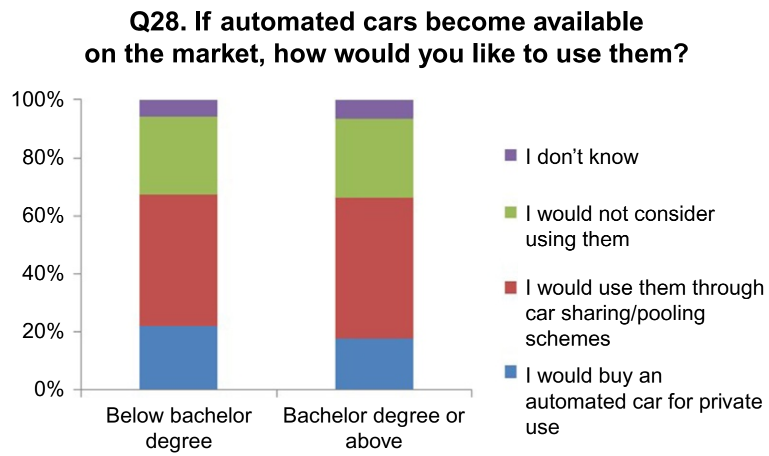

Fig. 3.35 Education received and attitudes towards owning/sharing automated cars.

However, respondents with higher education degrees showed higher interests in sharing automated cars than those with lower education degrees.

For the respondents with bachelor's degree or above, 49% stated that they would like to share automated cars, and 18% would like to own automated cars, compared with 45% and 22% for respondents with education below bachelor's degrees.

3.4.3.3.3 Experience of Riding the Automated Buses Demonstrated

Of the respondents, similar percentages stated that they would like to own an automated car regardless of having had riding experience of the automated minibuses demonstrated in Lausanne. However, of the respondents with ARTS riding experience (Fig. 3.36), 51% would like to share automated cars with others, compared with 47% for respondents without riding experiences.

3.4.3.4 Results of Stakeholder Survey

The objectives of the stakeholders' survey were to

- assess stakeholders' awareness and acceptance of the automated road transport system,
- investigate the expected impacts in relation with the role of each stakeholder and potential drivers and barriers connected with a spread implementation of automated mobility.

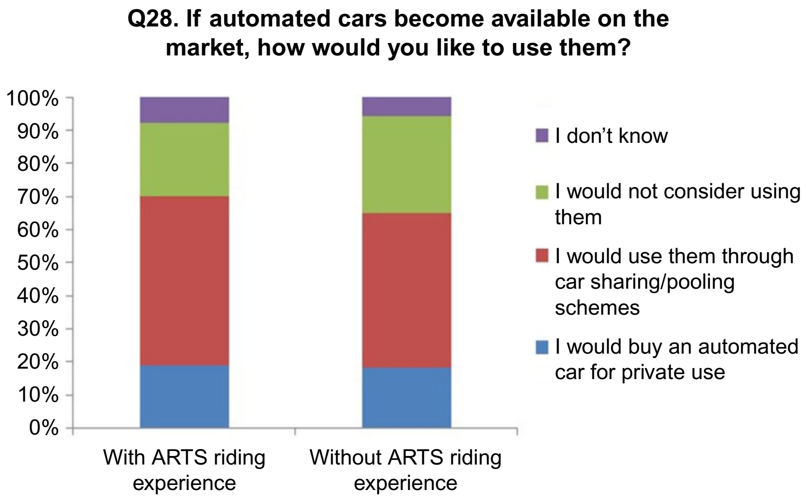

Fig. 3.36 Effects of ARTS riding experience on attitudes towards owning/sharing automated cars.

The stakeholder survey carried out in Lausanne was based on online survey using a structured questionnaire. The targeted people were stakeholders selected by Lausanne through an accurate process to ensure the best possible coverage of all relevant stakeholders' categories: local transport authorities, urban planning authorities, passenger transport operators, manufacturers and freight operators.

Concerning knowledge and attitudes towards automated vehicles, the totality of participants gave their positive opinion regarding automated vehicles (Fig. 3.37). Stakeholders answered also that automated vehicles can be an advantage mainly for safety, environment and transport efficiency. However, they showed some concern on the possible loss of jobs.

Respondents think that collective automated cars will have a positive impact on energy emission and will allow land saving (see Fig. 3.38). For the majority of stakeholders, automated vehicles will increase safety, comfort and convenience and decrease personal trip costs and fines (Fig. 3.39).

Also, 50% of them agreed that private automated cars will have negative impacts on land consumption, but not on energy emission.

Stakeholders considered automated vehicles in a future scenario as a useful technology principally for public transport, taxis and other on-demand services and freight transport (Fig. 3.40). As shown in Fig. 3.41, the majority of them also think that automated vehicles should not interact with other modes preferring a total segregation with dedicated lines (58%) or low-speed roads with pedestrians and cyclists (34%).

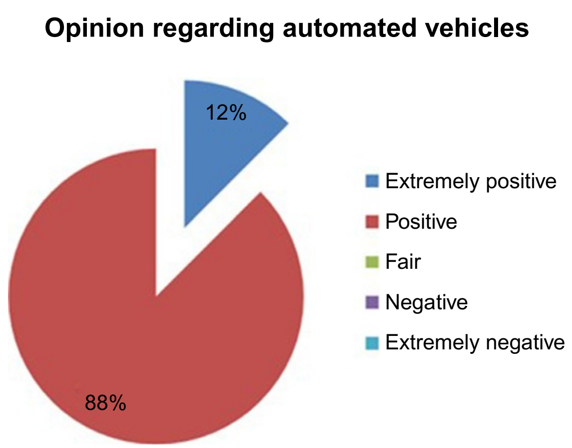

Fig. 3.37 Opinion regarding automated vehicles.

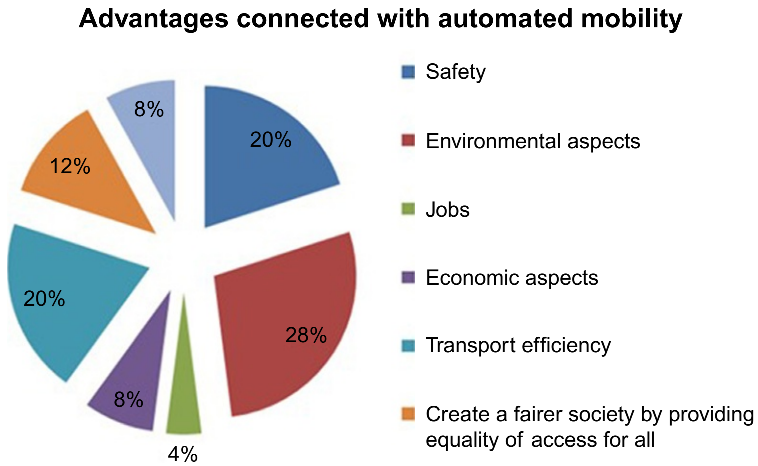

Fig. 3.38 Advantages connected with automated mobility.

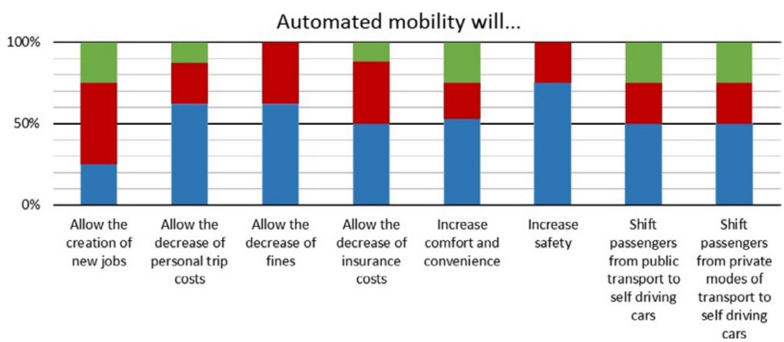

Fig. 3.39 Statements on automated mobility.

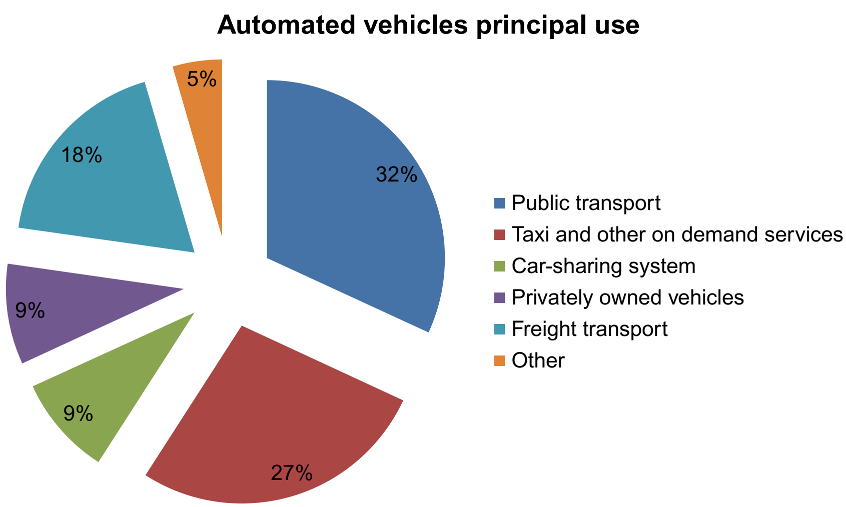

Fig. 3.40 Principal use of automated vehicles.

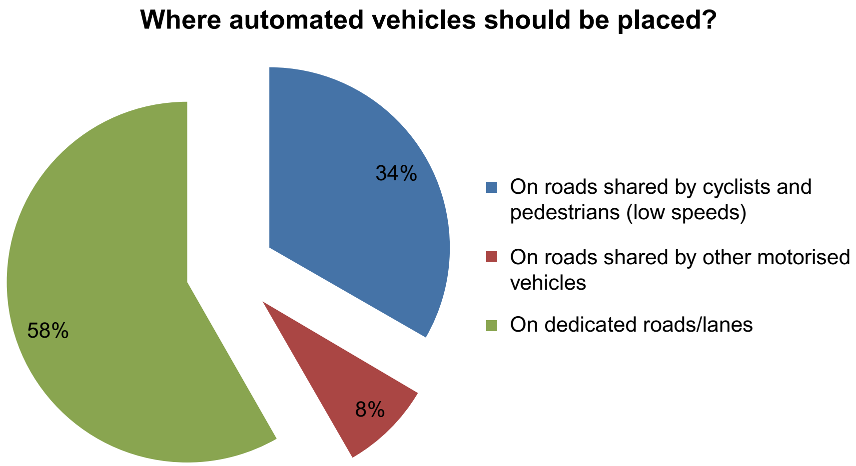

Fig. 3.41 Opinion on where automated vehicles should be placed.

The most enabling actions for a widespread implementation of automated mobility are shown in Fig. 3.42 and could be summarised as follows:

- Public authorities and urban planning operators should be proactive and include automated vehicle discussion in SUMP process.
- Private sector and automotive should not only think more about selling a service instead of selling cars but also help in investments, in avoiding negative modal shift and in considering elderly drivers.

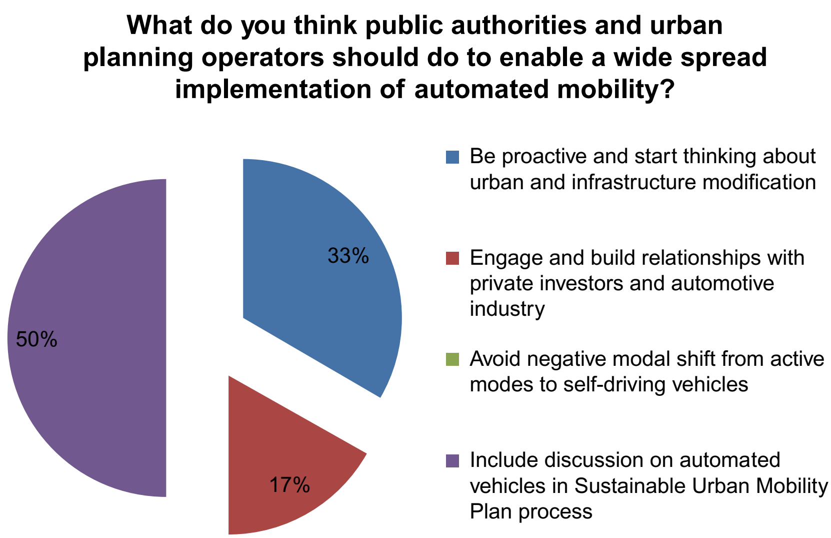

Fig. 3.42 Opinion on what public authorities and urban planning operators should do to enable a widespread implementation of automated mobility.

- Public authorities and private sector should think about automated vehicles as a mixed mode for passengers and goods delivery and study new successful business models.

The three most important drivers stressed were the commitment of key actors, the new potential offered by technology and accurate or visionary technical planning and analysis to determine the requirements for the implementation.

The most important barriers ranked by respondents were the analysis and proposals to change impeding rules, structures, legislation, etc., the different views and interests about the sustainable development of the cities and the involvement of key stakeholders.

In relation to that, the priorities for the research and development of automated vehicles in the future are as follows:

- Dissemination of current demonstration and evaluation results
- Further demonstrations of automated vehicle to increase awareness and acceptance of the general public
- Vehicle tests and evaluation under various traffic/road/weather conditions to ensure safety
- Large-scale field operational tests to collect empirical evidence of changes in modal choice behaviour

Regarding the next steps, several French-speaking Swiss cities are now testing autonomous shuttle (Fig. 3.43):

- Sion (Valais), two shuttles operated by Car postal
- Marly (Fribourg), operated by the local operator (TPF), start in summer
- Cossonay (Vaud), operated by the local operator (MBC), start in summer

Another important result is the success of a startup born in the CM2 project: BestMile, a software company specialised in the fleet management of autonomous vehicles, based on the Innovation Park of EPFL, which were funded with 5 mios Euros this year and operate several autonomous shuttle

Fig. 3.43 Three types of shuttle in three Swiss cities.

Fig. 3.44 The CityMobil2 vehicle.

systems around the world. Two alumni of EPFL have founded and managed this company with a great success (Fig. 3.44).

3.4.4 CONCLUSIONS

Key results found were as follows:

- Users appear to trust the automation capabilities of ARTS vehicles and feel safe inside them.
- About one out of five users were willing to pay more for ARTS than the current PT fare if the demonstration service would be implemented on a permanent basis. But as many as four users out of five were willing to pay more if the ARTS system would provide a door-to-door service, with one out of four willing to pay more than 100 EUR on top of the current PT fare.
- More than four out of five users thought that it is useful to implement the ARTS service on a permanent basis, but the majority of them thought that it would be better implemented on a different route.
- The EPSP survey shows that users have a relatively higher preference for ARTS (ASC positive ex ante and ex post) regardless of whether or not they had experienced the system.
- The impact on modal share of an extra fare applied to the ARTS service is significantly higher after experiencing the ARTS service, probably because of the low performances of the demonstration service.

- The top three benefits of automated cars that are most appealing to the people surveyed were 'reduce fuel consumptions and emissions' (64% answered very attractive), 'safer due to elimination of human errors in vehicle control' (60%) and 'increased mobility for the elderly, disabled and others' (58%). The top three issues most concerned by the respondents were 'equipment or system failures' (58% answered very concerned), 'risk of vehicle security' (54%) and 'risk of disclosing my location to others without my consent' (46%). Of the respondents, about two-thirds (67%) stated that they would consider using automated cars if they become available. Of the 'users' of automated cars, 19% would like to own automated cars, and 48% would like to share automated cars through services such as car sharing and pooling.

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CHAPTER 3.5

Evaluating ARTS in Oristano

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3.5.1 INTRODUCTION

Oristano was selected as a site for a demonstration during the first phase of the CityMobil2 project. The initial proposal was to run the test in the historical centre of the city. A plan of nine ARTS lines, coordinated with the existing urban transport network, was identified and added to the Urban Mobility Plan of Oristano. A line along the beach front was eventually chosen for the demonstration project due to its simplicity since, in that setting, the automated vehicles would interact only with pedestrians and nonmotorised vehicles. Subsequently, other cities participating in the CityMobil2 project have tested the system in promiscuity with flows of motorcars, benefiting from the preliminary findings of the Oristano demonstration.

3.5.2 CITY DESCRIPTION

3.5.2.1 The City Transport Problems

Oristano is a town of 32,000 inhabitants on the west coast of Sardinia, Italy. It has relevance at regional level thanks to its central position and the presence of important infrastructures such as the industrial zone, the port and the railway station. In addition to the main town, the city of Oristano includes several satellite villages: one of these, the touristic village of 'Marina di Torre Grande' (Fig. 3.45 shows a picture of main square), was chosen as the site for the CM2 demonstration.

The Urban Mobility Plan of Oristano highlighted how the existing public transport system was not adequate to satisfy the needs for sustainable mobility within the city. The city has good suburban connections served by six radial lines connecting the satellite villages with the city centre. Inside the city, however, the main attractors are connected by two circular lines that are inadequate in terms of itineraries (long and tortuous), travel times, headway and comfort at stops.

The urban plan highlighted that current public transport services should be improved in order to reach the social environmental and economic objectives. The problem is that the limited capillarity, low flexibility and high

Fig. 3.45 Piazza Eleonora, the central square of Oristano.

operational cost of the traditional collective transport system are not suited to the urban structure of the city that has a small size and low density. For this reason, the Urban Mobility Plan suggests to look for a new attractive and modern service that ideally must provide

- flexibility and 24/7 availability;
- capacity to perform door to door trips;
- user friendliness and access for the elderly and disabled;
- low emission and low landscape impact;
- low space consumption and compatibility with the narrow streets of the historic city centre;
- innovation to capture the curiosity and attention of the citizens (wow factor);
- low operational cost, especially personnel costs.

The characteristics listed above prompted the Administration of Oristano to look for a new transport vision for the city based on cybernetic transportation systems, in particular automated road transport systems (ARTS) such as cybercars for the city centre and group rapid transit (GRT) for specific urban and suburban connections. The CityMobil2 project provided an excellent opportunity to improve the knowledge in this frontier of urban transport and identify the most convenient and feasible solution for citizens' needs as suggested in Ref. [1].

3.5.2.2 The Selected Site and the Transportation Objectives

A network of nine lines was identified to define a potential citywide transport system based on automation technology. Some lines were identified to

Fig. 3.46 Overview of the potential sites.

intercept the car traffic that enters in the city centre from the surrounding villages, others to support the process of requalification of the historic city centre, and a third set to connect intermodal nodes such as the railway station, the port and the airport (see Fig. 3.46). Further two plans for touristic oriented lines were foreseen along the Marina of Torre Grande.

The network of automated transport lines was evaluated through 72 indicators (54 of which suggested by the CM2 project) in order to assess costs and benefits and the economic feasibility of the implementation. The site for the CM2 demonstrator was selected from this set of lines taking into account the compatibility with the objectives and constraints of the project.

At the end of the evaluation process, the decision was taken to implement the first ARTS demo for CityMobil2 in Torre Grande, during the summer months.

The location was chosen to exploit the long and straight beachfront boulevard (Fig. 3.47), which is completely pedestrianised and accessible only to service and security vehicles. The timing took advantage of the visibility and frequentation during the summer months, which provided both a more challenging environment and greater visibility for the demonstration.

3.5.3 THE CityMobil2 DEMONSTRATION

The Oristano demonstrator took place between June and September 2014. The first six weeks were dedicated to organisation and preparation. This was the first of the CityMobil2 pilot projects to take place. Two ARTS vehicles were provided by the partner Robosoft, arriving on July 10 and July 15 (Fig. 3.48).

Fig. 3.47 The itinerary of the demo in Torre Grande (1.3 km).

Fig. 3.48 Arrival of the first ARTS vehicle under the tower of Torre Grande.

The vehicles were baptised as 'Eleonora' and 'Mariano' after local historical figures. Being the very first demo of the project, and given the short time available to prepare the vehicles, several days were dedicated to setting up the vehicles and testing them on the route, prior to transporting passengers.

Robosoft also provided extensive technical assistance and training. The partner 'Comune di Oristano' took care of the infrastructure adjustments and logistics. The local transport operator and partner (ARST, Azienda Regionale Sarda Trasporti) provided the on-board personnel and installed the stops and the shelter. The partner MLab acted as coordinator

of the activities for the entire project. The demonstration was officially inaugurated on July 11 in the presence of authorities and stakeholders. Operation of the vehicles with passengers began on July 17 and ended on September 4.

3.5.3.1 Infrastructural Interventions

The route of the demonstration extended for the entire length of the beachfront boulevard. The boulevard is about 1.3 km long, almost entirely straight completely paved and flanked by rows of pine trees (Fig. 3.49). The asphalt strip is 7 m wide on average, flanked on both sides by ample curbs. On one side, there are low houses, on the other the beach. The area is completely pedestrianised; only service vehicles are admitted to collect garbage and stock service activities on the beach.

The infrastructure was prepared by repairing the asphalt where it was damaged by tree roots, setting up platforms at the two ends of the route to allow the turning back of the ARTS vehicles, and pruning trees to reduce interference with the GPS navigation system. Seven stops were placed on each side of the route—the two central ones are fitted with shelters (Fig. 3.50), the others with signs on poles.

A shelter was placed near the tower at the centre of the boulevard, to accommodate the ARTS vehicles, the recharge systems and tools for small repairs and maintenance. A temporary office and a GPS fixed antenna were set up at the top of the tower, and a kiosk near the vehicles' shelter was established to provide registration and information.

Fig. 3.49 The route of the ARTS where the asphalt was renewed before the demonstration.

Fig. 3.50 The vehicles in their shelter; the front desk kiosk is on the right, near the tower building.

3.5.3.2 Legal Aspects

The presence of on-board supervisors, able to stop the ARTS vehicles and take manual control of them if necessary, was required to comply with the road regulations as widely described in Refs. [2–4]. The supervisors were also necessary to guarantee security and safety of the persons transported. They were provided by the partner ARST and underwent a period of training prior to the start of operations with passengers (Fig. 3.51).

Being experimental, the ARTS vehicles had no formal registration as road vehicles. They were fitted with a 'test' registration plate for 'research and testing' use, to comply with road regulations in Refs. [5,6]. The use of ARTS vehicles did not formally constitute a public transport of passengers.

Fig. 3.51 Training of the ARTS drivers to operate as 'on-board supervisors' of the vehicles.

For this reason, any person wishing to take advantage of the service was required to register as an 'experimenter' by compiling a form in Refs. [7–9]. The experimenters were then allowed to board the vehicles and covered by third-party liability insurance.

3.5.3.3 Operational Aspects

The ARTS service was offered free of charge. This decision took into account that the entire route was located in a leisure area and the ARST system offered a public service of marginal importance. Imposing a ticket cost would also likely have reduced the number of users.

The vehicles operated from Monday to Saturday on two daily shifts of four hours each: from 9:30 a.m. to 1.30 p.m. and from 4 p.m. to 8 p.m. The afternoon break was set to match a period of low attendance and served to allow an 'opportunity charging' of the batteries (Fig. 3.52). During the demonstration period, the service was interrupted during three public events that attracted large crowds on the promenade.

During operations, the maximum speed was reduced from the initial limit of 20–12 km/h, because of issues with the strength of GPS signal and in order to enhance the safety of the vehicles and the pedestrians. A one-way ride was completed in 15–25 min, depending on delays due to obstacles and boarding–unboarding operations.

In the area of the pilot being completely pedestrianised, there was no need to limit vehicle traffic; no parking places were removed or relocated. The decision was taken not to place any barriers between ARTS vehicles and pedestrians, not even painted lines on the asphalt. This choice was taken to integrate the vehicles as much as possible into the existing environment,

Fig. 3.52 The ARTS vehicles on the seafront promenade of Torre Grande.

to minimise the impact of their presence. However, it soon became necessary to regulate the movement of service vehicles that accessed the area, especially in the morning: cleaning, garbage collection, maintenance, delivery of goods, etc. The operators working on behalf of the Administration of Oristano received service orders, whilst other operators were advised by the local police on the behaviour to maintain in the presence of the ARTS vehicles.

A public awareness campaign was launched early in the development of the demonstrator, consisting of press conferences; interviews with the partners; articles in the press, in the web media and on TV; publicity on the partners' websites; posters displayed in various parts of the city; a dedicated Facebook page on which many questions were received and answered; and an FAQ web page. The demonstrator was explained to commercial operators of activities along the boulevard, discussing any possible conflict. On July 16, the TRB conference in San Francisco, the United States, was connected to the site, and the delegates were able to witness the operations live. On July 31, a delegation of stakeholders from the main public transport companies, research centres and municipal administrations in Sardinia was invited to visit the demo and be informed of its characteristics.

3.5.4 ARTS OPERATION AND EVALUATION

The ARTS operation in the demonstrations has been evaluated on the basis of the CityMobil2 framework, reported in Ref. [10].

3.5.4.1 Technical Feedback

The demonstrator itself immediately proved successful, despite some shortcomings that limited its performance. The population and visitors of Torre Grande readily accepted the presence of the ARTS vehicles, and the local business operators were also positive about the experiment. The most positive outcome was that no one seemed to feel in danger from the ARTS vehicles travelling totally unprotected among pedestrians. Small children were left free to play as usual, and the care of the parents was sufficient to avoid any dangerous situation. The attitude of the parents themselves was relaxed and generally more oriented towards curiosity and interest than fear.

Another initial concern also proved to be largely overestimated, specifically the fear of 'stunts' performed by older children and teenagers to test the capacity of the ARTS vehicles to stop in conditions of danger. After some low-risk stunts in the first days of operation, this curiosity faded away, and the ARTS vehicles were accepted as part of the environment.

Fig. 3.53 In the evening, the promenade became very crowded, and operations of the ARTS were interrupted.

From a technical point of view, the major initial concern was the duration of the batteries. However, battery life proved more than sufficient to cover an entire day of operations (8 h), and the remaining charge at the end of a day was never below 70%, even without opportunity charging during the midday pause.

The two ARTS vehicles covered a total 1700 km in 36 days of operation. During this time, there were no accidents and no major faults, and the vehicles performed very well in terms of safety and reliability. The only major concern was the loss of GPS signal when passing under the canopy of bigger trees, which caused the vehicle to stop, normally with a light braking action. In this case, the guidance of the vehicle had to be converted to manual mode until the GPS signal was recovered (Fig. 3.53).

3.5.4.2 User Interviews on Acceptance and Quality of Service

At registration, the experimenters received a questionnaire to be filled in, as seen in Ref. [11]. During the pilot, a total of 339 questionnaires were returned, providing important information on the behaviour of passengers in respect to such a novel means of transport. A number of canvas tote bags with the CityMobil2 and demo logos were handed out as presents and in particular as an incentive to hand back a filled-in questionnaire.

The response of the population and visitors exceeded expectations. By the end of the demonstration pilot, more than 1600 people had registered as experimenters, and many complained that the experiment had been terminated too early. The total number of persons transported (number of boardings) registered by the supervisors was 2600. This meant an average

of 72 passengers per day of operation. On average, each registered experimenter travelled 1.6 times.

The ARTS service was greatly appreciated by the elderly persons who lived in Torre Grande. Many of them used it regularly to reach the shops or centres of social activity, thus sparing them a long walk under the sun, often with heavy bags. Unfortunately, the vehicles had no provision for disabled passengers, and this was a flaw in a system otherwise much appreciated by persons with a walking impairment.

Children also liked the ARTS system very much and often prompted the adults accompanying them to register for a ride. On board, they were curious and seemed to understand very well the novelty of the system. One lesson for the coming demonstrators of this project is to involve children as much as possible. Activities dedicated exclusively to children and, if the period is right, to schools, will generate a high level of interest, awareness and familiarity with the ARTS systems. The enthusiasm of children will easily spill over to adults and generate a virtuous circle of interest and appreciation.

The data collection provided a large amount of information, both concerning the social variables (composition of the sample of individuals who used and assessed the system) and acceptance of the system (stated and revealed preference surveys). The information comes from three data collection bases:

- **Registration sheets**. The registration of the passengers as experimenters in order to allow them on board. This database includes date of registration and personal details. Total number, 1603.
- **Questionnaires**. Compiled voluntarily and autonomously by ARTS passengers. It includes date of compilation, personal data and answers to stated preference and revealed preference questions. Total number, 339.
- **Drivers' logs**. The logs compiled by the drivers during the operations. These include data about vehicle travel, timing, distance, battery charge level and boarding and disembarking passengers at each stop (Fig. 3.54).

3.5.4.3 Financial and Socio-Economic Evaluation

The plan of the whole automated transport network (constituted by nine lines) was evaluated through an economic and financial analysis to verify the convenience of its implementation for regular operation. In particular, the economic-financial model evaluated the feasibility against the cash flow, capital cost, maintenance cost, administration and tariff return and collective economic benefits over 30 years of operation. Financial efficiency was elaborated by means of synthetic indicators: the financial net present value (FNPV) and the financial internal rate of return (FIIR).

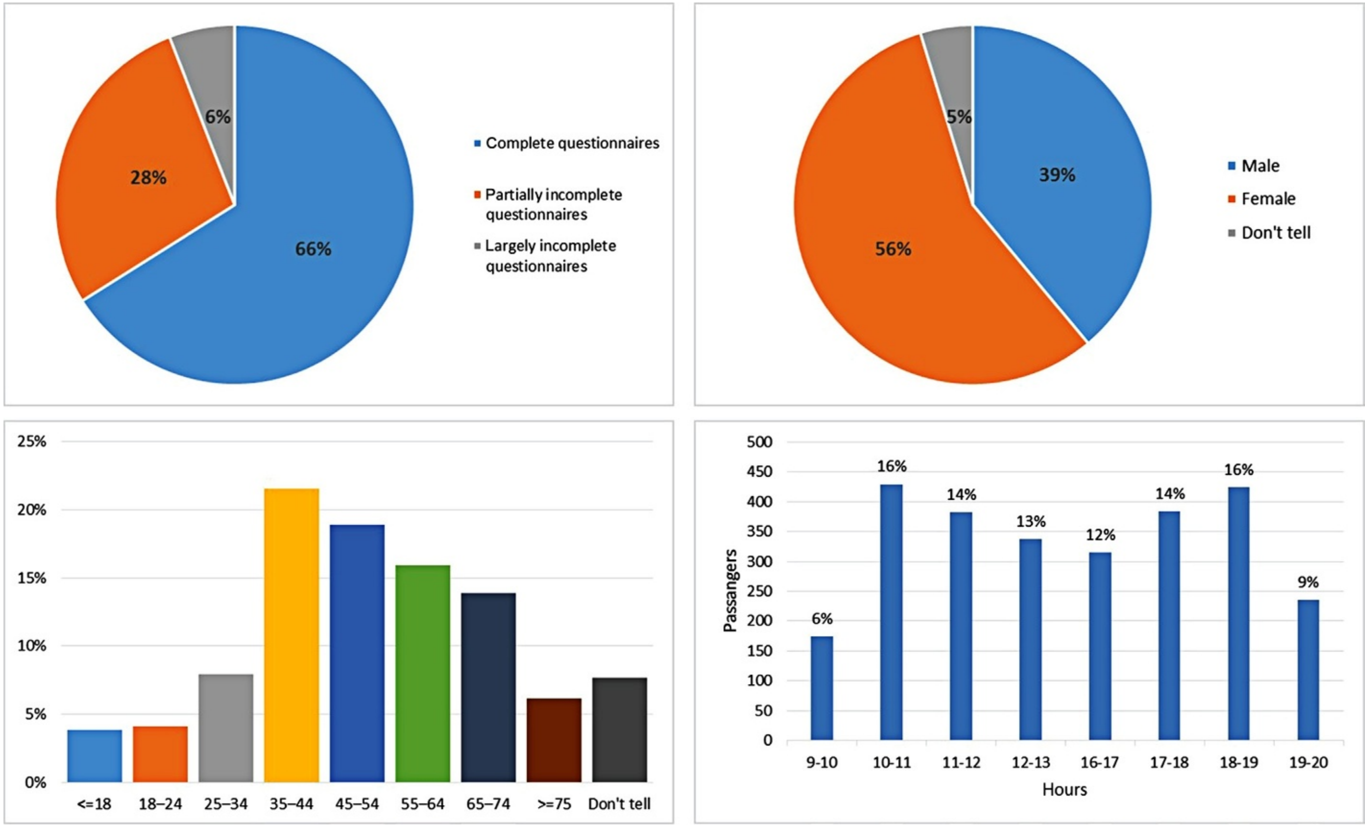

Fig. 3.54 Selected analysis from surveys.

The economic analysis, as opposed to the financial one, took into account many objectives and potential impacts on the community, positive and negative, for both direct and indirect users (externalities) of the system. These are air pollution, greenhouse gases, noise pollution, safety and congestion (time lost). As for the financial analysis, economic efficiency has been elaborated by the expected net present value (ENPV) and the economical internal rate of return (EIRR).

The ENPV proved to be extremely positive showing a residual value of over 10,902,000€ at the end of 30 years (assumed useful life of the infrastructure) and an EIRR equal to 16.51% (values above 6% are considered positive).

3.5.4.4 Lessons Learnt

This demonstrator was the first of the CityMobil2 project. As such, it did not benefit from previous on-field experience, and it had a short duration. However, it provided a large amount of information and yielded several important lessons, which were learnt and treasured for the following demonstrators and activities. The most important lessons learnt from this experience concern the interaction between the system and the public, whether they were directly involved in the demo, such as on-board supervisors and experimenters, or just part of the social environment surrounding it.

The choice of not marking the route had both positive and negative consequences. On the positive side, there was total integration of the ARTS vehicles in the environment, where they moved among the pedestrians, cyclists and children without any measure to warn of their presence. The persons strolling along the waterfront boulevard simply acknowledged the presence of the vehicles and stepped aside to let them pass. Mutual disturbance was minimal.

On the other hand, a lack of signage meant that persons could not know in advance if they were invading the path of the vehicle. This was not a significant issue with pedestrians, but proved to be for service vehicles, which were often parked in spaces 'invading' the tolerance area of the ARTS vehicles.

The demonstration had a good resonance on the local media, and it was also presented on national and international media. However, the media were alerted only twice: once at the beginning of the demonstrator and again at its end. Given the interest in this experiment, it would have been wise to 'recall' the media during the demonstration to present the functioning of the system and provide some intermediate results. This would have

increased awareness of the media about the project and likely generated a cascade effect by media outlets quoting other media.

The vehicles themselves suffered very few problems, most of which were readily solved. No issues came directly from the power and control subsystems. However, the loss of GPS signal when the vehicles travelled under the thicker canopy of the larger trees showed that an ARTS system cannot rely solely on GPS guidance, but must instead have at least two systems working together, and each should be able to take over if the other should fail. In all the subsequent pilots, a second guidance system (SLAM, simultaneous localization and mapping) was installed and worked in parallel with the GPS system.

3.5.5 CONCLUSIONS AND FUTURE PLANS OF THE CITY

The Oristano ARTS demonstration represented an important step towards the implementation of autonomous vehicles in a nonsegregated environment. It facilitated all the subsequent tests of the CityMobil2 project and allowed them to avoid a number of shortcomings that were resolved or highlighted during this pilot as cited in Refs. [12–14]. For the city of Oristano, it represented a step towards a more sustainable plan of mobility and an opportunity to be a player in the field of autonomous vehicle operations.

As a result of the pilot, Oristano has now added a network of autonomous vehicles in its Urban Mobility Plan. This network will complement a renewed main network of 'person-driven' public transport vehicles and will improve its efficiency and the accessibility it offers. This is an important step because for the first time a local administration has included such innovative technologies in its mobility plan with the aim of improving the quality of its public transport system.

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CHAPTER 3.6

Evaluating ARTS in Vantaa

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3.6.1 INTRODUCTION

Existing public transportation system in Helsinki region is based on heavy rail services (train and metro), which provide the backbone of the public transport system. Bus services supplement the rail services. Bus services include feeder bus routes, service routes and cross-town services. Direct radial bus routes to the centre of Helsinki serve areas that are not served by rail.

The feeder traffic from a railway station to residential and working place areas is thus depending on the quality of bus services. At least in the evening, the interval is quite long, which does not support the use of public transportation. To reduce the use of private cars, better public transportation system has to be developed.

The largest project, what was going on when the CityMobil2 project started and which improves mobility in Helsinki region, was Ring Rail Line project. It was completed in June 2015. The 18 km Ring Rail Line with five new stations in the first phase provides an important public transport link between the main line and the local urban line. It also provides a rail link to the Helsinki-Vantaa Airport, under which the rail goes in an 8 km-long tunnel. The Ring Rail Line has been an essential part of the urban line network that improves public transport in the entire Helsinki region. The line connects existing and new residential and working place areas.

Kivistö is a new suburban centre along this Ring Rail Line. Five years ago, the centre area was a dark forest. In a new area, the city wants to promote all kinds of new sustainable ideas from energy saving to grass roofs, from designing to cycling and from housing innovation to new innovation in transportation.

Ring Rail Line is a perfect transport mode when travelling to the Helsinki Airport, the centre of Helsinki or any other areas in Helsinki region, but it does not solve the problems of sustainable feeder traffic to the stations and sustainable internal traffic in residential areas such as Kivistö. A principle solution for feeder and internal traffic is to arrange traditional bus services with the typical long interval in which nobody is satisfied. The automated bus traffic with reduced traffic costs and better service could be one solution.

The city of Vantaa has studied the use of automated people and goods mover (APGM) in airport business park areas and in feeder traffic to Ring Rail Line. This study was completed in 2005. Vantaa participated in reference group of CityNetMobil project, which was supported by the EU. Vantaa has organised a cybercar showcase and a CityMobil conference in May 2009. It was the first time when automated vehicles were presented in Finland. After the showcase, Vantaa has carried out Syöksy Research Project to carry out a study to increase the mobility of electric vehicles. Thus, Vantaa has shown a large interest in automated traffic. Vantaa has been a forerunner in automated vehicles for public transportation in Finland [1,2].

3.6.2 CITY DESCRIPTION

3.6.2.1 The City Transport Problems

The city of Vantaa is part of Helsinki Region Transport System. Public transportation is organised by the Helsinki Region Transport. Helsinki Region Transport is interested to develop new transportation modes as automated transport because it is not possible to provide good public transportation services for inner and feeder traffic to local railway stations for every residential or working place area. ARTS vehicles could support the objectives of the Helsinki Region Transport System Plan and other strategies as well. That is why Helsinki Region Transport with the city of Vantaa was willing to introduce the use of ARTS vehicles as part of public transport and preferably in all climate conditions.

3.6.2.2 The Selected Site and Transportation Objectives

There were two areas to choose, when the demonstration proposal was under preparation and when a longer half year demonstration was under consideration: Aviapolis next to the Helsinki Airport and a new suburban centre Kivistö that lies west from the airport. Both areas have a new station along the Ring Rail Line that was opened in July 2015. To have a 6-month demonstration, ARTS vehicles had to be equipped with winter conditions. Because the requirement for the ARTS vehicles in CityMobil2 project was to be able to run only up to −5°C, it was not possible to arrange a large-scale demonstration in the city of Vantaa. Due to the requirements for segregated route, Aviapolis was abandoned. From infrastructural view of point, it was easier to arrange a segregated route in Kivistö. Another reason that encouraged a small-scale demonstration to be held in Kivistö was the housing fair in summer 2015.

The city of Vantaa is developing a new suburban centre called Kivistö for over 30,000 inhabitants. To promote a new housing area in Finland, the city of Vantaa decided to have the housing fair in Kivistö. This concept is widely used for new housing areas in Finland.

The construction of roads in Kivistö started in the year 2012 and houses 1 year later. The first new residential buildings were erected in the housing fair area.

Initially, the purpose was to have a route from the housing fair area to Kivistö station and furthermore continue to the west. The route could not continue from the Kivistö station to the west, because the new housing area in the west was just under construction in the summer 2015 with no inhabitants. The construction work was late due to general financial situation in Finland. So, the route has to be cut to Kivistö station.

At the same time, a new rail connection from Helsinki centre to Helsinki Airport was under construction. It is called Ring Rail Line, because it shapes a heart figure where the airport is at the top and Helsinki centre is down at the tip. So, the airport can be reached from the west and the east. Kivistö suburban centre is along this new rail line with a new station.

The main objective of the demonstration was to promote this new suburban centre and this new rail line. The city of Vantaa wanted to promote the idea that the visitors would arrive to the housing fair by the new Ring Rail Line that was just opened, only a week before the opening of the housing fair. About one-third of the passengers arrived by train to the housing fair.

Visitors generated transportation demand to transport them from the Kivistö station to the housing fair entrance and back. Even though a traditional nonstop bus service was arranged, ARTS vehicles would introduce smart mobility on how we will be transported in the future. CityMobil2 demonstration would bring more publicity and would show a totally new innovation for large public.

In demonstration, it was possible to test a new service and concept and to have feedback from the visitors. In longer term, the objective is to provide a better transport service in Kivistö and later in other suburban areas in Vantaa.

3.6.3 THE CityMobil2 DEMONSTRATION

3.6.3.1 Infrastructural Interventions

The demonstration route followed bicycle road along the Ring Rail Line. The route is owned by the city of Vantaa. The road was brand new, and it

Fig. 3.55 Passengers are waiting for ARTS vehicle at the housing fair bus stop.

was opened for public use straight after the demonstration. There were two CityMobil2 bus stop stations: at the local Kivistö train station and by the entrance of the housing fair (Fig. 3.55).

There was no need to cut the traffic during the demonstration. No special permission for the use of the road was required as the demonstration area and road were planned in cooperation with traffic planning and land-use unit of the city of Vantaa. These units make all decisions on how city-owned roads are used for public traffic.

Route was easy to segregate by fence, whilst on the southern side, there was the railway with a high fence. On the northern side, there was either forest or logging side for city development, and on this northern side, a temporary fence had to be erected.

The following infrastructural works had been made just for demonstration:

- At Kivistö railway station, stairs from street level down to ARTS service bus stop to enable safe and comfortable entrance for passengers
- Paving for the bus stop at the housing fair end to accommodate bus stop
- Temporary bus shelter and bench for passengers at the housing fair bus stop
- Info boards and custom-made signs along the demonstration route requested by ARTS vehicle manufacturer
- Depot for the ARTS vehicle maintenance and storage
- Fences to segregate the route
- Other equipment required for demonstration

- Setup and maintenance phase, such as Internet connection and basic automotive tools

Vantaa demonstration infrastructural adjustment and integration was accomplished on time on 9 June 2015, just before the testing of ARTS vehicles begun.

3.6.3.2 Operational Aspects

The demonstration operated at the same time as the housing fair was opened, thus every day from 9 July to 9 August 2015 from 10 a.m. to 6 p.m. On August 5 and 6, the demonstration has extended the operating time until 8 p.m. due to the extended opening time of the housing fair. The testing and preparation were done from 9 June to 8 July 2015.

ARTS operated from Kivistö railway station to the housing fair entrance. The trip was free of charge for passengers. The length of the demonstration route was 1.0 km. Demonstration route map is presented on Fig. 3.56.

There were four ARTS vehicles in service [3]. For the first two week, two ARTS vehicles were used to carry passengers. For the last two weeks, the service was operated with three ARTS vehicles. Two ARTS vehicles were in service in off-peak hours.

There was a great challenge to make the ARTS vehicles running in a tunnel. There is a 178 m long tunnel (Fig. 3.57) under a main street and a square on the ARTS route.

The following tests and setup activities had to be carried out:

- Upload of the SLAM reference MAP in each ARTS vehicle
- Tests of localisation function
- Tests of collision avoidance function (emergency stop, decision-making, safety chain and high-level functional safety)
- Setup of the trajectory (path following)

3.6.3.3 Legal Aspects

The automated road transport system demonstration proposals of the city of Vantaa and the demonstration route were planned in close cooperation with the Finnish Transport Safety Agency and the Ministry of Transport and Communications. The legal framework in Finland was examined before the demonstration. No changes have been made for regulations and legislation related to ARTS vehicles. Finnish road traffic legislation complies with the Vienna Convention on Road Traffic [4].

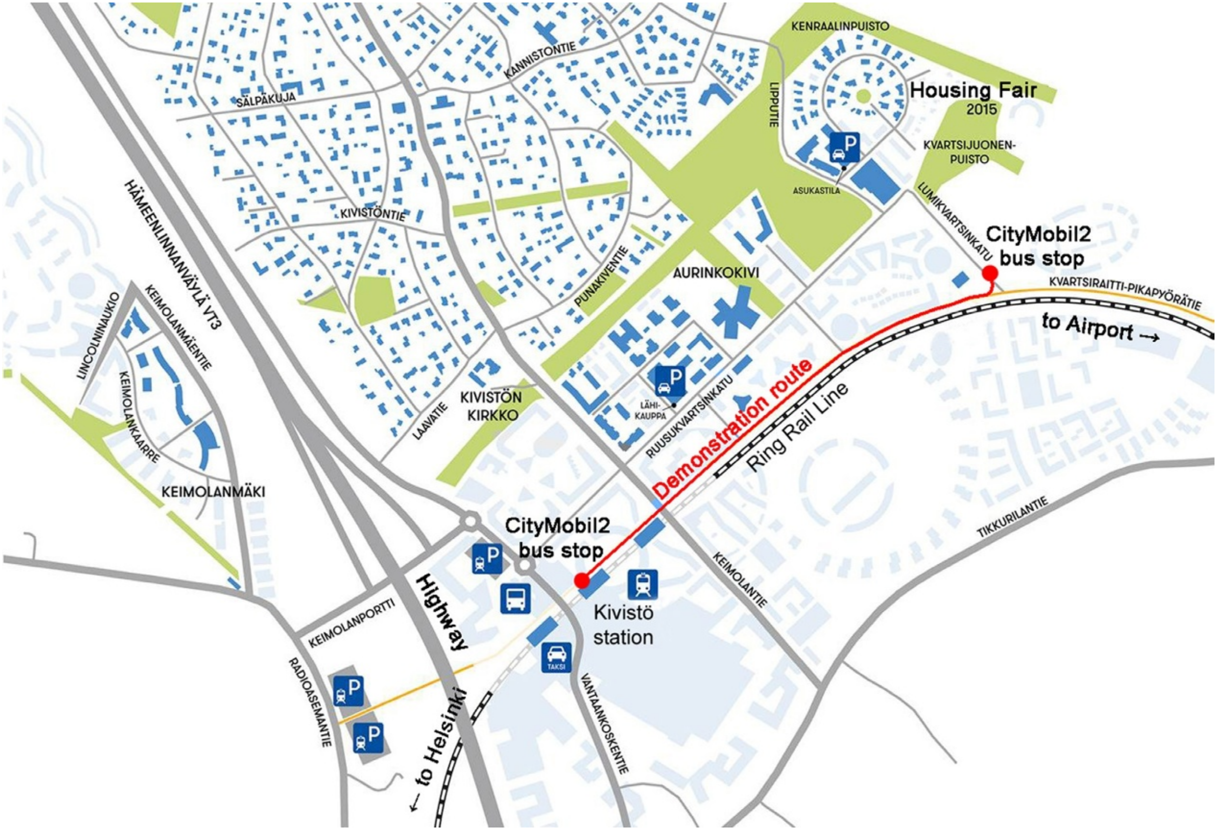

Fig. 3.56 ARTS route map.

Fig. 3.57 The tunnel on the ARTS route.

Fig. 3.58 The bicycle route by the Ring Rail Line.

As a result, the demonstration was possible to arrange with a driverless vehicle in a restricted area. The route did not cross with any other traffic, and no other road users (vehicles, pedestrians or cyclists) were allowed on the same route. Since the aim of the Vantaa demonstration was originally planned to organise a trail fully without a driver or other operative staff on board, segregated route was chosen. The segregation meant that the route was surrounded by the fences to block the route from other users (Fig. 3.58).

During the demonstration phase, new guidelines for automated vehicle testing trials were published by the Finnish Transport Safety Agency (Trafi) [5]. Trafi interprets that after all, the legislation allows driverless vehicle testing trials in Finland without any regulation changes. It is all about interpreting existing legislation in a new way so that the driverless vehicle routes don't have to be segregated but the ARTS vehicles can be tested on the street network in mixed traffic. However, an ARTS vehicle must fulfil certain requirements, and it must also always have a driver as a failsafe. This new interpretation of regulation was discovered too late for the demonstration.

3.6.4 ARTS OPERATION AND EVALUATION

The ARTS operation in the demonstrations has been evaluated on the basis of the CityMobil2 framework, reported in Ref. [6].

3.6.4.1 Technical Feedback

Technical operators filled shuttle log sheet every day. Shuttle log includes data from the ARTS vehicle and system, such as miles travelled, battery discharge, total number of passengers on each ARTS vehicle and a list of emergency stops [7]. The demonstration did not generate any accidents or major technical problems [8]. Some technical issues occurred, and the manufacturer was made aware of these problems. Summary of emergency stops is presented in Table 3.14.

3.6.4.2 User Interviews on Acceptance and Quality of Service

There were 139,000 visitors at the housing fair, and 19,021 of them used ARTS; thus, 13% of visitors tested ARTS [9]. Housing fair visitors came all over Finland. Most, of course, were from Helsinki region. There were a lot of visitors from neighbouring countries Estonia, Russia and Sweden

Table 3.14 Recorded incidents

Total emergency stops	52
Rain	5
Grass	1
Passing another shuttle	5
Component crash	12
Program completely crashed	17
Button pressed by operator	12
Loss of localisation	16
Screen freeze	16
Other	24

Table 3.15 Number of responses on each survey

Survey	Total responses
Ex Post Evaluation Questionnaire	420
Ex Post Stated Preference Questionnaire	198
Questionnaire to a Wide Public	118
Stakeholder Survey	20

due to good ferry and train connections. The number of passengers tells that CityMobil2 got a lot of experience from many people from babies to grandparents, from city to countryside people.

Four different surveys were organised. The surveys and number of responses are in Table 3.15.

The objective of the **Ex Post Evaluation Questionnaire** of ARTS users was to collect information from the ARTS users' mobility behaviour and assess users' level of satisfaction with Ref. [10]. Instructions to access the survey were not given to everyone leaving the bus but only to those who wanted to take it. When a technical issue occurred, the staff guides were busy with the customer service task and could not distribute so many instructions.

According to the responses, passengers were found to have been very satisfied with the ARTS service overall. Most of the respondents rated different aspects as good or very good. Waiting time and on-board time from stop to stop received the lowest ranking, as both the speed and the capacity were relatively low especially at the beginning of the demonstration, when only two vehicles were operating at the same time. Nevertheless, the amount of unsatisfied passengers was extremely low, and the amount of satisfied passenger was very high.

Most of the visitors had a positive and interested attitude towards automated vehicles, and there were no adverse comments. The most important thing for passengers was to get from the station to the housing fair, not the transport mode. They were willing to take the ATRS vehicle if the queue was not too long. If a conventional bus was available more immediately, many chose that instead of waiting for 15 min or even more for ARTS. Good satisfaction with the service indicates that people would be willing to use automated transport services in the future.

The **ex post stated preference** (EPSP) questionnaire survey carried out in Vantaa was based on face-to-face interviews using a structured questionnaire [11]. Key results found were as follows:

- Whilst users appear to trust the automation capabilities of ARTS vehicles and feel safe inside them, they still need the physical presence of a

company operator inside the vehicle to feel confident to be protected in case of attacks or emergency situations.
- About one-half of users were willing to pay less for ARTS than current public transport alternatives, and just 9% of users surveyed were willing to pay more for ARTS than current public transport services.
- Ninety percent of users thought that it would be useful to implement the service on a permanent basis. However, the majority of them thought that it would be better to implement the ARTS system on a dedicated route.
- The EPSP survey results showed that users have a relatively lower preference for ARTS regardless of whether or not they had experienced ARTS.
- In the ex post model estimation, the socio-economic attributes such as gender, age and level of education did not affect user decisions.

The **Questionnaire of a Wide Public** was mailed to all the households (1113) in Kivistö and distributed to all exhibitors (200) of the housing fair. According to the Questionnaire of a Wide Public, passenger security was the one of the most concerned issues for automated buses especially during night-time services. For the automated minibuses demonstrated, the most supportive role was to complement public transport as feeders/distributors. The attitudes were positive towards the implementation of automated vehicles in car-sharing and car-pooling services. For the respondents, the most confident benefit was 'reduced pollutant emissions' (53% answered 'very likely'), followed by 'reduced energy consumptions' (50%) and 'smoother vehicle movements' (41%). The attractiveness of automated vehicles reduced with age, implying that increasing technology awareness in the population will enhance the desirability of automated vehicles of all types.

All participants in the **Stakeholder Survey** gave a positive opinion regarding automated vehicles. Stakeholders answered also that automated vehicles can be an advantage mainly for safety, environment, transport efficiency, economic aspects, and to create a fair society (access for all). Stakeholders considered automated vehicles a useful technology in a future scenario, principally for public transport, taxis and other on-demand services and freight transport. The majority also considered that automated vehicles should interact with other modes preferring the space sharing with other motorised vehicles, although almost 20% preferred dedicated lanes. The main message was anyway that public authorities and urban planning operators should be proactive, avoid negative modal shift, rethink parking

space allocations and include automated vehicle discussion in sustainable urban mobility plan processes [12].

3.6.4.3 Transport and Environmental Data on ARTS Performances

Four technical persons were operating the system, and eight persons were serving passengers as guides. The operators were trained by the manufacturer and were able to solve technical issues with the vehicles. The guides collected feedback from passenger for the evaluation. In total, 19,021 passengers were transported by the service; Table 3.16 shows some stats; Figs 3.59 and 3.60 show some passengers at stops and during boarding operations.

Table 3.16 Vantaa demonstration statistics

Days of operation	31
Total ARTS vehicle kilometres, km	3962
Average kilometres per day, km	128
Total number of passengers	19,021
Max persons transported per hour	116
Max persons in one day, August 6	1013
Average persons per day	614
Average persons per kilometre	4,8

Fig. 3.59 Passengers are boarding to ARTS at Kivistö station stop.

Fig. 3.60 Passengers are boarding to ARTS at the housing fair stop.

Vantaa demonstration energy consumption is calculated from daily discharge percentages using the following formula:

$$\text{Daily discharge} = \text{total discharge } (\%) \times \text{battery capacity } (16\text{ kWh})$$

Total energy consumption is only an estimation, not accurate measurement. In total, 756 kWh of energy was used on Vantaa demonstration (Table 3.17). After a normal 8 h operational day, the batteries had 30%–40% of their remaining energy. Thirty percent was the lowest discharge level of the batteries instructed by the manufacturer.

3.6.4.4 Financial and Socio-Economic Evaluation

The demonstration proposal for the city of Vantaa can be described as small-scale demonstration. The duration of the demonstration period was 1 month. The total costs of demonstration were about 330,000€.

Table 3.17 Energy consumption

Total energy consumed, kWh	756
Energy consumed per passenger, kWh	0.04
Average battery discharge, %/km	0.86
Maximum discharge per day, %	78

Most of the costs arose from personnel costs. For the demonstration, the following infrastructural work (98,067€) had to be carried out: stairs down from street level to ARTS bus stop, elimination level differences in bicycle route temporarily, rent of fences, rent of depot, signs and info boards, bench for passengers, bus shelter, electricity and paving of the bus stop at the housing fair. Other expenses (13,117€) consist of insurance, internet, materials, clothing, rent of computers and other minor costs.

3.6.4.5 Lessons Learnt

Currently, interest in automated vehicles is huge in Finland. Media representatives are very willing to write related articles. Articles related to the Vantaa demonstration were written in a positive and interesting way and were very welcoming, and many people were informed. The demonstration passed the news threshold very well.

The relatively slow speed of the service and sometimes the long waiting times at the stops did not result in either negative publicity or articles with a negative tone. Automated vehicles are new, and most of the people experienced autonomous vehicle for the first time. In the future, when autonomous vehicles are demonstrated, reporters and passengers will probably be more critical of level of service factors, for example, operational speed as the vehicles will then be less innovative.

To compare the results of the Ex Ante and Ex Post Stated Preference Questionnaires, it is remarkable that in both cases, we have obtained the same result in terms of relatively lower preference for ARTS when the two competing systems have identical travel time and fare attributes. Travel time might have been a frustration for the passengers due to very slow speed of ARTS vehicle. Many visitors waited that these vehicles are as rally vehicles because the Finns are rally people.

The Finns are not willing to pay anything extra because they have learnt the ticketing system in Helsinki region. You can transfer from transportation mode (bus, train, tram, ferry and metro) to another as many times as you like when the ticket is valid. A single ticket is valid for 60–100 min depending on the number of zones.

Even though the mixed traffic would be possible for ARTS vehicle, almost 20% of stakeholders preferred dedicated lanes. If dedicated lanes are required, it would be too expensive for public government to construct new infrastructure for a new transportation mode. Use of ARTS vehicle must reduce the use of private cars, thus promoting increasing the share of public transportation in traffic. Dedicated lanes are reasonable on those

places where there is a lot of traffic. Major cities already nowadays promote bus traffic by bus lanes with traffic light preference or dedicated bus streets.

3.6.5 CONCLUSIONS AND FUTURE PLANS IN THE CITY

The demonstration was the first time in Finland when automated vehicle was used to transport people in real life. The experience the city of Vantaa got was remarkable. Nowadays, in 2017, also other cities as Helsinki, Espoo and Tampere are interested in automated vehicle. These cities have a project going on using the same vehicles as were in Vantaa in 2015.

The city of Vantaa is still interested to have ARTS vehicle in public transportation, at the first phase in Kivistö and Aviapolis. Kivistö centre is growing all the time and would be an excellent area to test ARTS vehicles in feeder traffic and inner traffic round the year. Also, in Aviapolis, the civil aviation authority considers to use ARTS vehicle to transport passengers between parking area and terminals. Also, there would be a great need to transport people from Aviapolis station to offices, hotels, a shopping centre and residential areas. ARTS vehicles would replace hotel shuttle buses.

But before that, the next step is to test ARTS vehicles in winter condition. Public transportation must work round the year in any weather condition. If the ARTS vehicles work in snow falls or in slippery weather conditions or in cold winter days as −30°C , ARTS vehicle technology has solved one big barrier [13]. The city also needs to know how the city has to improve its infrastructure. How the ARTS traffic will flow in the winter? Do you have to put sensors, cameras or other equipment on the road? Or signs along the route when there is dark forest around you?

Stakeholder Survey showed that the priorities for the research and development of automated vehicles in the future are as follows:

- Dissemination of current demonstration and evaluation results
- Further demonstrations of automated vehicle to increase awareness and acceptance by the general public
- Vehicle tests and evaluations under various traffic/road/weather conditions to ensure safety
- Large-scale field operational tests to collect empirical evidence of changes in modal choice behaviour

Also, the results of Stakeholder Survey suggest that more pilot projects with winter testing are needed before the ARTS vehicles are ready traffic in Vantaa and in Finland.

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CHAPTER 3.7

Evaluating ARTS in San Sebastian

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3.7.1 INTRODUCTION

The cybernetic transportation systems (CTS) are an urban mobility concept based on two ideas: the car sharing and the automated capabilities with door-to door solutions [1,2]. These systems help to solve the limitation of automated vehicles in smart cities, increasing the acceptability from different users.

In recent years, the advanced driver assistance systems (ADAS) and automated driving capabilities confirm different improvements for road situation monitoring and some partial and full control on vehicles. These advances allow people unable to drive due to age, ability or illness, to have access to new areas previously restricted by them. The automated road transport systems (ARTS) are part of the objectives pursued by the intelligent transportation systems, which use different perception, communication and control technologies in real environment, to improve the driving process in urban areas.

European cities face four main problems related to mobility: congestion, land use, safety and environmental issues. One of the main causes of such problems is the car-ownership rate. The centres of large cities address this issue combining efficient mass transits with car restriction policies, but peripheral areas and smaller cities remain dominated by private cars.

Cybercars are automated vehicles related to the door-to-door transportation solution. The project CityMobil (2006–11) has demonstrated that automation of road vehicles can lead to different transport concepts [3,4], from partly automated car-share schemes through cybercars and personal road transport (PRT), which can make urban mobility more sustainable (see Refs. [5–7]). However, CityMobil has highlighted three main barriers to the deployment of automated road vehicles: the implementation framework, the legal framework and the unknown wider economic effect [8–10].

For this reason, in 2012, CityMobil2 project addressed these barriers and finally removed them [11]. To smooth the implementation process, CityMobil2 will remove the uncertainties, which presently hamper procurement and implementation of ARTS.

On one hand, CityMobil2 features 12 cities, which will revise their mobility plans and adopt ARTS, wherever they prove effective. Then, CityMobil2 will select the best five or six cases (among the 12 cities) to organise ARTS demonstrators. The project will procure two sets of automated transport systems and deliver them to the five or six most motivated cities, which will host demonstrations for a period of 3–6 months.

The following pages describe the last large demonstration in San Sebastián city, during 3 months. The demonstrator shown in the city was oriented to assess the full potentials of cyber cars for their mobility following a common methodology in order to generate same indicators and lead to full cost-benefit analyses of the alternative solutions based on automated transport systems.

3.7.2 CITY DESCRIPTION

3.7.2.1 The City Transport Problems

An important fact should be noted that the park has more than 3500 employees, to whom we must add visitors coming daily for labour causes. In the site selected, the number of workers is more than 1300.

Despite the fact that mobility in Miramon Technology Park is mainly labour mobility, there is in this area of the park the Science Museum and the Basque Culinary Centre Foundation, which attract many people daily during lunchtime, besides the regular events organised in the park and the visits to companies located there.

They are characterised by the use of private transport (car) or walking through the park, since currently, there is no public transport within the park and city buses only reach the limits of it, leaving no services to the majority of companies.

Mainly, the greater mobility is early in the morning and in the afternoon (peak hours are from 08:00 to 09:00 and from 17:30 to 18:30), since employees usually don't go home at mealtime. As for the mode of transport, four urban and two suburban public transport lines serve this technology park, although none of them gets into the park, so the car is by far the predominant mode of transport (67%). There are also four suburban public transport lines that do not stop too far from technology park.

3.7.2.2 The Selected Site and Transportation Objectives

The demonstrator site selected for SS city (Miramon Paseo Mikeletegi) covers the west area of the park. In this area, there are several buildings

with 66 technology-based companies, including the park management itself. Moreover, near this area of the park is located the Museum of Science, the Basque Culinary Centre Foundation and the Restaurant Miramon Arbelaitz. So, according to the potential three different sites initially considered, the final area was called 'site 1', and it is shown in Fig. 3.61:

Fig. 3.61 Area of demonstrator for San Sebastián city.

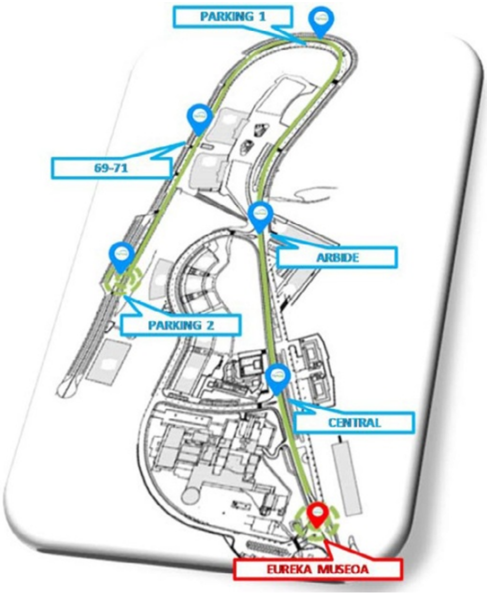

Fig. 3.62 Round trip with six stops.

The aim of the demonstration was to operate an automated public transport service, during 3 months, with an electric automated bus (driver-less), with a capacity of 10 people circulating along the technology park. It is the first demonstration not only in the Basque Region but also in Spain.

This system is offered as a last-mile mode transport service—with a distance of 2 km round trip and six stops—to businesses in the park, connecting the automated buses with the conventional urban public transport system, which currently only goes as far as the edge of the park (Fig. 3.62).

In this way, improving the public transport service could increase the number of bus users and consequently decrease the use of private vehicle (currently around 67% of the work displacement).

Additionally, as described in Ref. [12], the following aspects could be highlighted about the practical feasibility:

- The demand estimation was the most important due to 51% of demand, and mobility was concentrated in this area, not only workers but also visitors, events, etc., generated by the technology park activity. Additionally, headquarter of the Miramon Park was in this area where a lot of events are held, and the Science Museum, having more than 150,000 yearly visitors, was located too.

- Besides, there were different groups of people, who focus on the urban planning and communication system within the park and public responsible for urban mobility; from the technical point of view, it would be easy to segregate ARTS from normal traffic in this site. Besides, there was an underground car park ready to be used and a charging point and garage during the demonstration where the wireless communications had a very good quality.
- It was considered too that workers in this site were more related to be involved on using this type of advanced transport systems, mainly because most of them participated in the mobility committee of the park and/or supported it from the start.
- Additionally, there were several entities involved in (and supporting) the demonstration, ensuring the success in the performance, which pertains to the regional government, municipality and technology park management.

3.7.3 THE CityMobil2 DEMONSTRATION

3.7.3.1 Infrastructural Interventions

The correct and safe functionality of the system was needed to amend several sections and adjust some infrastructures. The major changes were as follows: to move several car parks at the end of the course, creating two broad areas for parking; to modify the speed of travel, limiting the maximum speed to 30 km/h and in some cases changing the direction of traffic; and the last one to set lanes for the automated bus, segregated in some parts of conventional traffic. Other minor changes were made like painting signal roads and parking spaces and installing pivots and traffic lights to prioritise the automated buses (see Fig. 3.63).

Likewise, a control centre has been enabled to monitor all the time the system and a depot for parking, maintenance and charges of the batteries.

3.7.3.2 Operational Aspects

The public transport service operated from Monday to Friday in working hours (from 07:00 to 19:30) with a frequency of 8 min in peak hours. A last mile public transport service in the park (no transportation service in this area had ever existed) was offered that connected automated buses with the local bus services at the park entrance. The total distance covered was about 1.2 km with six marked stops along the route.

The demonstration used a total of three automated and full-electric minibuses, provided by the French company Robosoft. These vehicles had a maximum capacity of 10 people and were adapted to disabled people.

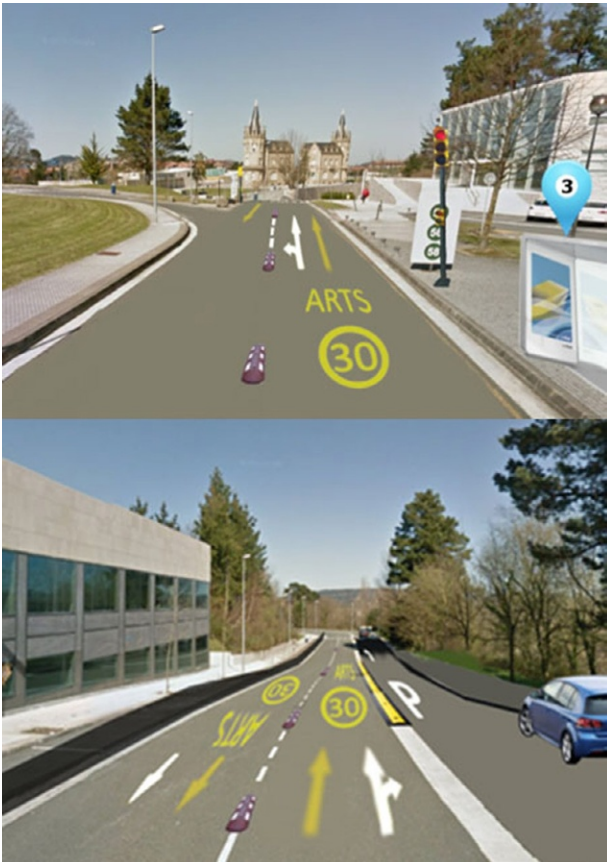

Fig. 3.63 Infrastructural interventions.

During the operation of the automated bus, an operator was on board as a support staff, attending to the users and resolving eventualities and emergencies that might occurred. Likewise, the operator had the option to take manual control of the vehicle to prevent incidents or dangerous situations.

The maximum vehicle speed in no case exceeded 30 km/h and was electronically and software limited to ensure the safety of passengers and by-standers. The average operating speed was 10 km/h. During the operation, the vehicles were monitored at all times from a control centre installed in the park. This monitoring system was controlled by the manager through a 3G modem and allowed seeing at real time to all vehicles on their itinerary and indicating specific instructions to one of them, for example, remaining at the stop until another vehicle came or a default situation happened.

To keep vehicles in good condition, a daily maintenance routine was followed, based on the following steps: cleaning the lasers, checking and charging the batteries and the controllers and checking the tyres and the security laser. Once a week, fill the batteries in water if needed after a full charge.

3.7.3.3 Legal Aspects

The Spanish legal framework, until a year ago, did not allow the circulation of driverless vehicles on the national roads or on the urban ones [13,14]. For this reason, the Traffic General Directorate (DGT) published on the 13th of November 2015, an instruction for the authorisation for tests or research studies carried out with automated vehicles on roads open to general traffic. Besides the requirements of the instruction, the procedure to be followed in order to obtain the authorisation to circulate the automated buses was established.

Finally, the procedure to get the authorisation is very simple and easy. The whole process takes a maximum of 3 months:

- The first step was to get the certification and the homologation of the vehicles that was issued by the INTA as national certification authority of vehicles. This certification was based on the DGT instruction.
- The presentation of the demonstration operating conditions and the definition of the security measure had been taken. The dossier with all the information was submitted to the authorities involved at national level (DGT).
  - A required application must be filled out with the data and information of applicants and the identification of the type of vehicle used for testing (dimensions; mass; power; safety features, e.g. emergency stop system; electromagnetic compatibility), etc.
  - A report describing the tests and that includes the different aspects of the demonstration was provided: brief description of the technology incorporated in the vehicle, overview of training schemes for automated vehicle operators, identification and detailed description of the area requested for conducting the tests, and general description of the operation of the public transport service.
  - Liability insurance (SOV is included) and insurance for the vehicles.
  - Payment of the fees of the Central Traffic Headquarters (Form I4).
- Request to the Provincial Head of Traffic of San Sebastián for the permission of circulation for the vehicles (four) and the licence plates.
- The DGT requested to the council of San Sebastián the authorisation to circulate on the established urban route. The local decision-makers,

in particular the mobility area, have to issue a provisional authorisation to occupy public road that must be approved by the Local Government Board, once the municipality of San Sebastián permits it to circulate in the public road, which does not require to modify the municipal regulations.

- Lastly, DGT issued the final authorisation to circulate the vehicles of Robosoft (3) and EasyMile (1).

3.7.4 ARTS OPERATION AND EVALUATION

The ARTS operation in the demonstrations has been evaluated on the basis of the CityMobil2 framework, reported in Ref. [15].

A public transport service using automated vehicles was demonstrated in San Sebastián, with three automated minibuses running on a loop route in Miramon Park from 7 April 2016 to 30 June 2016. The on-site tests of the ARTS vehicles began on 1st of March 2016. Considering the challenges faced in running automated vehicles in an urban environment, it was decided to implement the ARTS route making some infrastructural changes [16,17].

The total number of users was 2,753 during the 60 days of the ARTS demonstration, with an average of 48 users per day. This equated to more than three users per circulated hour.

It can be said that Miramon is not too close to the most visited areas of San Sebastián. Miramon is more frequented by tourists on weekends, when vehicles are not operating.

After a site risk assessment carried out by site coordination [18], a maximum speed of 10.8 km/h was set up for the operation of ARTS vehicles to ensure the safety of the system. All the ARTS vehicles were operated with a member of staff on board. The role of the on-board operator was crucial to ensure safety through intervention in case of deviations or malfunctions of the system. Because of the training delivered by the local teams, operators were very well received by users as they could give information on the system, explain the context of the demonstration and reassure the users as to the safety of such innovative transportation systems.

3.7.4.1 Risk Management

This section describes the ARTS risk evaluation in the last CityMobil2 demonstrator in San Sebastián. It would address the main safety issues regarding the proposed track and vehicles, specially focused on maximum speed allowed in order to not present unacceptable risks.

The main effort of this chapter is to found and evaluate the risks related to the different itinerary zones depending on their specific characteristics. Interoperability with other stakeholders (cars and pedestrians) is going to be the main issue to deal with.

First, hazards in Miramon Park and their related risk were identified. Then, based on the technical deliverable 'D15.3, Specification for obstacle detection and avoidance', the safety maximum speed per zone was calculated. Finally, adverse climatological conditions situations were considered.

This risk evaluation was based on rational behaviour of the stakeholders involved, not taking into account hazards derived by unpredictable actions.

The highest risk was to have an accident with another road user: manual vehicle at high speed or to run over a vulnerable road user. The only solution to reduce the risk level in these situations is to segregate the automated vehicles from the regular ones, which was not possible because the aim of the demonstrator is to integrate the automated vehicles in urban environment. For this reason, specific maximum speed for automated vehicles in order to avoid any hazard was presented.

Analysed hazards were location-dependents (intersection, curves, slopes, etc.). So, there were a set of different safety requirements in terms of speed depending on the zone the ARTS were operating. Later, a specific analysis of conflictive locations was carried out.

ARTS detection area is divided in three areas. Emergency area, in which any obstacle is detected in this area, will occasion an emergency stop. Safety area, in which the ARTS decelerate to avoid any obstacle in the emergency area. In the obstacle detection area, ARTS embedded equipment predicts the trajectory of an obstacle that may enter in ARTS planned path. To avoid collision risk, ARTS shall adapt velocity or even make an emergency braking.

Fig. 3.64 shows the stop distance (d_{stop}) covered by ARTS in order to avoid any collision. d_{stop} is the sum of safety distance (d_{s}), reaction distance (d_{r}) and braking distance (d_{brake}).

The following are the equations that are going to be used to calculate maximum speed in each segment:

$$d_{\text{brake}} = -\frac{v^2_{\text{max}}}{2 \times a_{\text{max}}}$$

$$d_{\text{stop}} = d_{\text{reaction}} + d_{\text{brake}} + d_{\text{s}} = v_{\text{max}} \times \left(\tau_{\text{refresh}} + \tau_{\text{process}} + \tau_{\text{reaction}}\right) - \frac{v^2_{\text{max}}}{2 \times a_{\text{max}}} + d_{\text{s}}$$

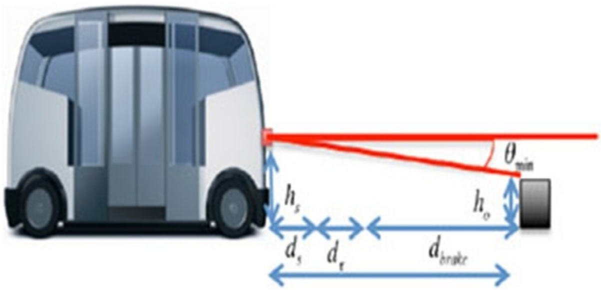

Fig. 3.64 Stop distance.

Stop distance is the distance needed to make an emergency brake to avoid any collision. This distance is defined by the obstacle detection range, so we consider the stop distance between the vehicle and the hypothetical obstacle.

Reaction distance is calculated as the sum of the overall control system reaction time τ_{reaction}, the processing time τ_{process} and the time between two sets of data τ_{refresh}. τ_{refresh} must be smaller than 20 ms; τ_{process} smaller than 40 ms and τ_{reaction} smaller than 300 ms are considered. Finally, the overall reaction time must be smaller than 360 ms.

Arbitrarily, 1 m of safety distance was set. The maximum allowed deceleration value to maintain comfort standards is $a_{\text{max}} = -1.5\,\text{m/s}^2$. Table 3.18 shows the maximum allowable speed in certain conditions.

Bad weather conditions affect the perception and driving behaviour. Depending on the conditions, maximum velocities must be revised. In adverse conditions, it is necessary to use longer braking distances to slow the vehicle to keep comfort and safety standards.

Table 3.18 Speed table

Type of zone	Vmax
Roundabout	8 km/h
Straight path	20.7 km/h
Pedestrian cross	8.5 km/h
Parking exit without traffic light	8.5 km/h
Parking exit in the same lane with traffic light	8.5 km/h
Parking exit in the opposite line with traffic light	10.67 km/h
Curved path	20.7 km/h
Intersections	8.5 km/h
Fixed obstacles	7.3 km/h

3.7.4.2 Technical Feedback

The accumulated number of hours of operation was 809 h during the whole period of demonstration, a total of 1434 laps to the route. The total distance travelled was about 3441 km during the whole demonstration period in San Sebastián. All key indicators in the following sections are the ones described by Ref. [19].

Weather conditions have influenced the performance of the vehicles. Under some adverse weather conditions, technological sensors such as the LASER have been affected. So, rainy days have impacted negatively on the ARTS performance. Fortunately, there have not been many rainy days in which the service has been stopped because of bad weather (only 6% in rainy days).

One important factor was the batteries discharging that depends on some factors like the weight that the vehicle is moving, which means that it is important to know how many people are inside the vehicle. On the other hand, another factor to take into account is that the path is not always flat and the consumption in the uphill is greater than in the rest of the route.

Taking into account the zone where the demonstrator was carried out, interaction with other road users leads to some incidents, and the most frequent were bad parking that interfered in ARTS route. Anyway, it is more remarkable that by the final stage of the pilot, other road users' behaviour got worse, taking more and more risk, whilst they got used to drive among ARTS (more than 20% of the incidents are reported by the operators).

Vehicle-related failures are seen more important due safety-related issues. Until today, vehicles are not able to run in auto mode because the front laser detects raindrops as obstacle and stops the vehicle. More remarkable and worrying are the incidents related to lose of route and lose of breaks. By the end of the demo, the trees were full of leaves and may interfere in the communication between vehicle and antenna and lead to route loses. Break lose was always reported during the downhill slope and in fact is the most risky incident reported.

3.7.4.3 User Interviews on Acceptance and Quality of Service

The main objective of this study was to gain a better understanding of users and their transportation needs and to collect feedback to assess the demonstration on the basis of different criteria. The surveys were administered through face-to-face interviews in two phases with a total of 375 participants.

For the vast majority of users, the demonstration was their first experience with automated vehicles, and their purpose was to test it. The respondents

were mostly students and workers. Most of the users declared having used the system only once just to test it as their trip purpose.

Mobility Board, TV, press and mouth to mouth were the main awareness sources. Actually, workers were aware of the service before the launch of it because the Mobility Board of Miramon Park was in contact with all the companies located in the park and gave information to spread to their employees.

In general, satisfaction regarding ARTS is good, rating the comfort and safety very positively. The criterion of vehicle speed requires particular attention for future experiments as it was the most poorly rated. Even so, 67% of the users declared that they would use a similar service in the future.

Concerning the comments registered by operators, people complained about the speed of the vehicle and the uncertainty of the service. Working as regular service, they were not able to know when the vehicle would reach the stop they needed, and this made many users reluctant because they argue that they could not trust the service.

3.7.4.4 Transport and Environmental Data on ARTS Performances

In urban context transport, the impact on road capacity is expected to be particularly favourable in the collective scenario for rural/touristic areas. Regarding environmental impact, ARTS are positive with the exception of infrastructure modifications. Decrease in energy consumption and emission impact is expected positive, and urban changes would lead to a land saving that could be requalified in the city context.

3.7.4.5 Financial and Socio-Economic Evaluations

As affordability is connected with accessibility, vehicle cost and business model are key issues. Rural areas tend to have low and dispersed demand; the cost-efficiency ratio is uncertain. On the other hand, touristic areas could attract many foreign passengers. Subsides would need to be considered like other public transport modes.

Social impacts are positive in collective automated scenarios. The impact in road safety is considered positive despite the initial negative estimations. In terms of urban planning, with fewer vehicles, the actual situation would change, and new policies to increase life quality could be applied. The introduction of a new way of transport would need a transition phase to overcome the fear generated by uncertainty and make users feel comfortable. Subsidies would need to be considered to assure affordability.

Economic impacts in terms of new jobs, employment, personal trip cost, fines and insurance are positive, with the exception of employment in old jobs, where the introduction of ARTS would decrease the car sale. In case of parking fees, the reduction of the fees is beneficial for trip cost but would affect negatively in the administration budget. It is important to remark that improving accessibility in remote areas would enable economic development. However, the timeline is uncertain, and it would take a whole generation for full change.

3.7.4.6 Lessons Learnt

ARTS has been implemented successfully in a mixed road, interacting with other road users. Currently, few results are reported on automated buses to provide public transport services on public roads without segregation of traffic. The demonstration of ARTS vehicles in Miramon proved that it is possible to provide public transport service by operating automated buses in urban areas.

On the other hand, although the service worked, it was not efficient enough. Route was composed of mixed and dedicated lanes that slowed down vehicle commercial speed. Targeting a competitive service, we have learned that nowadays, segregated lanes are the way to make this service efficient. In this case, with the available technology, we could achieve an increase in speed and frequency and at the same time increase safety segregating different road users as widely described in Refs. [20,21].

But we have to take into account that this kind of service is thought to compete with walkers, so an interesting research would be to compare distance and time between walking and automated vehicle transport, so we can determinate a range where people are willing to take ARTS.

After the infrastructural changes were made and ARTS was introduced, it was noticed that the previous road users started to make bad choices because they were used to previous infrastructure configuration. It was observed that they needed some time to adapt to the new environment, but by the end of the demonstration, they were too used to drive among ARTS, and they started again taking bad choices, in this case regarding safety. They became too risky.

3.7.5 RESULTS

A public transport service was successfully demonstrated in Donostia/San Sebastián with three automated minibuses running on a loop route in Miramon Park (2.4 km). During the 3-month demonstration, a total of 2753 people have tried automated vehicles (Fig. 3.65).

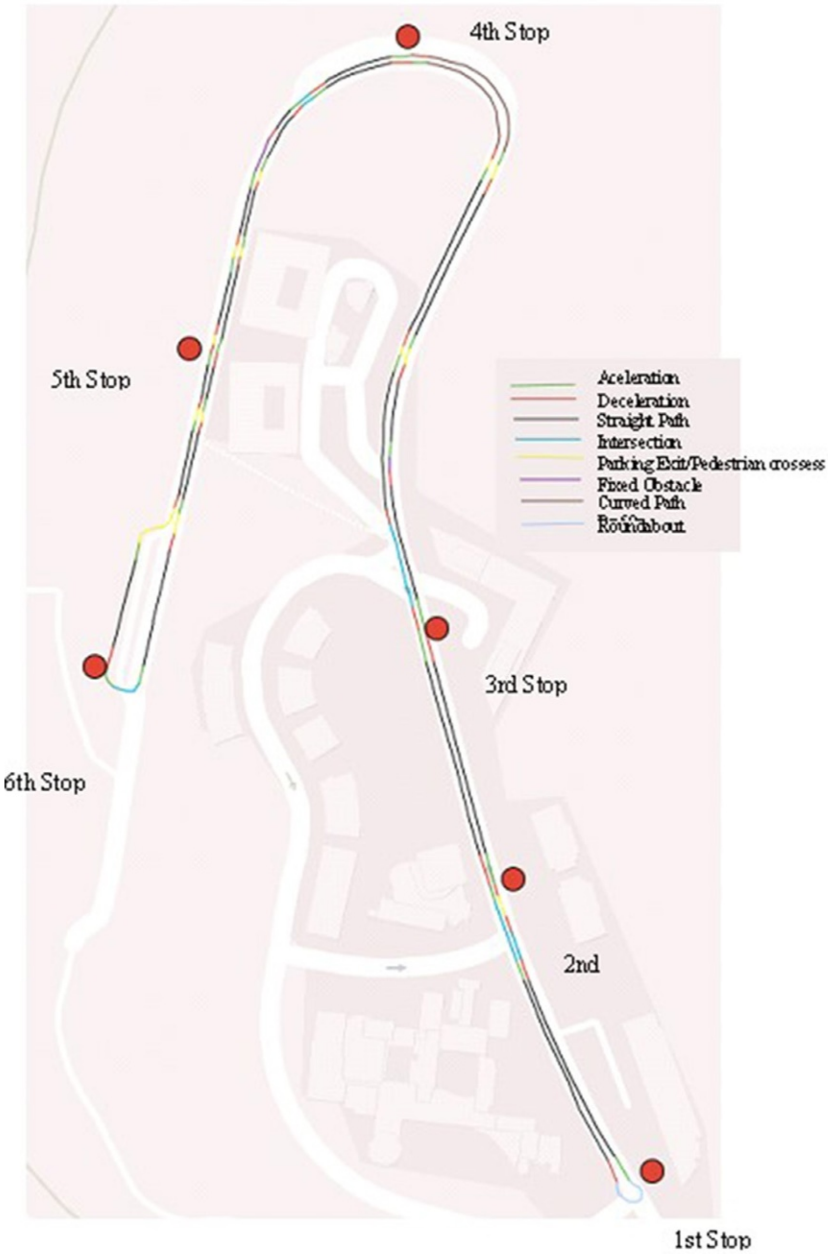

Fig. 3.65 Speed profile in the map.

Although some weather conditions have influenced the performance of the vehicles, that is, rainy days have impacted negatively on the ARTS performance mainly due to LIDARs that have been affected, fortunately, there have not been many rainy days in which the service has been stopped because of bad weather. Only 6% have tried the demonstration in rainy conditions.

For the vast majority of users, the demonstration was their first experience with automated vehicles, and their purpose was to test it. So, the satisfaction regarding ARTS was good, rating the comfort and safety very positively. The criterion of vehicle speed requires particular attention for future experiments as it was the most poorly rated. Even so, 67% of the users declared that they would use a similar service in the future (Fig. 3.66).

Concerning the comments registered by operators, people complained about the speed of the vehicle and the uncertainty of the service. Working as regular service, they were not able to know when the vehicle would reach the stop they needed, and this made many users reluctant.

The discharge of the batteries depends on some factors; one of them is the weight that the vehicle is transporting, so it is important to know how many people are inside the vehicle (same results were found in Ref. [22]). Another factor to take into account is that the path is not completely flat, so in the uphill, the consumption is greater than the rest of the route.

Two hundred eighty-six occurrences were reported by the operator, of which almost 73% were related to vehicles. So, although the technology available nowadays lets us launch ARTS services, it is important to keep researching and developing in order to reduce this risk gap.

Most frequent incidents regarding other road users were bad parking that interfered in ARTS route. Anyway, it is more remarkable that by the final stage of the pilot, other road users' behaviour got worse, taking more and more risk, whilst they got used to drive among ARTS. These incidents were more than 20% of the reported incidents by the operators.

Although nowadays few results have been reported on automated buses to provide public transport services on public roads without segregation of traffic, ARTS have been implemented successfully in a mixed road, interacting with other road users.

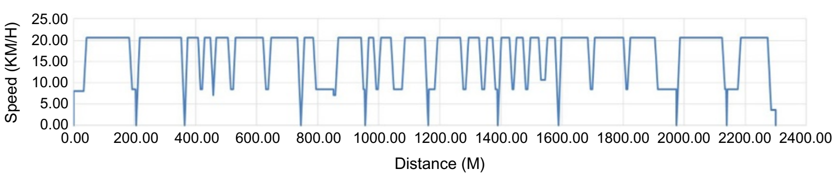

Fig. 3.66 Speed profile in the demonstration of San Sebastián.

3.7.6 CONCLUSIONS AND FUTURE PLANS IN THE CITY

The fact that the automated public transport service—CityMobil2—has been tested in a complex environment where private cars, pedestrians, delivery companies, cyclists, bikers, conventional urban transport, garbage trucks, etc. coexist has allowed to test this type of vehicles in different scenarios [23].

Regardless of the complex environment and most of the routes on a shared lane—mixed traffic, interacting with other users—the demonstrator has been implemented successfully, without any incidents that proves that technology and automated vehicles are ready to be introduced as permanent services in cities or urban areas. Anyway these permanent services require some additional improvements related to operating speed in order to provide a competitive and attractive transportation service. To avoid speeding up and lowering safety levels, it is best to run on dedicated lanes until having a more consolidated service and being more confident for the new users. Other aspect to improve is to check extensively the obstacle avoidance system in every spot, where the two most important tests concern the precision of the lane keeping and the obstacle avoidance.

A remarkable achievement has been to establish the legal procedure that must be followed to obtain an authorisation to run automated vehicles in urban settings and the agreement among all public entities involved in it. Another aspect to be highlighted is the need of the support of key players (public and private) to ensure the success of an innovative experience of these characteristics: finance, available resources, legal aspects, communication and awareness campaign, etc.

Furthermore, the demonstration in San Sebastián has proved that it is possible to provide public transport service by operating automated buses in urban areas and its acceptance by park's workers and people who visited the park to test by themselves these automated vehicles.

In conclusion, it has been demonstrated that automated transport system is a mobility solution for the last-mile transport in an urban area with a strong demand for transportation concentrated at peak hours. Furthermore, interest and acceptance of the automated transport system have been shown by citizens, regardless of age and occupation, and by public administrations. The support and involvement of the different public administrations at national, regional and local level is a clear signal of the interest in implementing these systems as a solution for urban mobility, both in San Sebastián and the rest of Spanish cities. According to this, they will continue to contribute to the development of these systems to make this type of transportation a reality in the near future.

ACKNOWLEDGEMENT

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CHAPTER 4

Lessons Learnt From Cross Comparing City Applications

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CHAPTER 4.1

Assessing User Behaviour Around ARTS

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4.1.1 SOME IDEAS FROM THE CAR-MAKING INDUSTRY

Road users, especially vulnerable road users, will (presumably) behave differently around an automated vehicle than around a manually driven one; for instance, many VRUs try to establish eye contact with the driver of the vehicle, and in the case of driverless vehicles, there will be no eyes to get in contact with.

Car makers have already started to work on ways for the automated vehicle to communicate with other road users.

Mercedes for instance have shown vehicles projecting road signs (zebra crossing) on the infrastructures to show to the pedestrian that the vehicle is yielding and projecting a stop sign to give a similar message to an incoming car.

Nissan has expressed a similar concept with a writing interface for other road users. Similarly Mitsubishi proposes a shuttle like vehicle which projects on the ground to show the door is opening, the forward direction and the backward direction in case it is reversing.

4.1.2 CityMobil2 MEASURING OTHER PEOPLE BEHAVIOUR

The first small demonstrations of fully automated vehicles on the pedestrian streets, back in the early years of the century, were often theatre of reckless pedestrians jumping in front of the automated vehicles just to test their emergency braking capability.

CityMobil2 demonstration has had some of this behaviour at the very beginning, but the users were quickly used to the automated vehicles to the point of considering them as very reliable and trustworthy.

3-D cameras provided by VisLab were installed on one of the demonstration vehicles to measure the reactions of the people to automated vehicles.

As shown in Figs 4.1 and 4.2, besides taking pictures, the cameras have the capability of classifying objects and positioning them in space. Such feature was used to identify the moments in which pedestrian and bikers were close to the vehicles and to see their behaviour on camera.

Fig. 4.1 A porter crossing the street in Oristano in front of the automated vehicle without even looking at it.

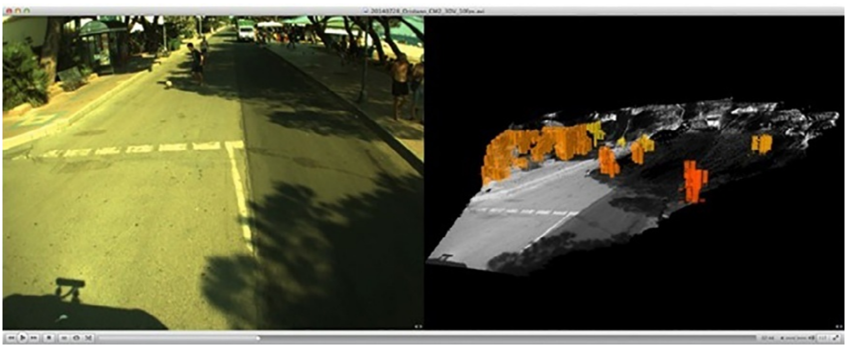

Fig. 4.2 Kids playing soccer in front of the automated vehicle and waiting for the ball to go out before stopping and letting the vehicle pass.

Both Figs 4.1 and 4.2 are taken in the second month of the very first demonstrator in Oristano and show how people by then were so used to automated vehicles and their respect for pedestrians that they cross in front of it without even looking at it (Fig. 4.1), or even more surprising, in Fig. 4.2, kids playing soccer continue to play until the ball goes out before stepping aside and letting the vehicle pass.

The general results of this activity can be synthesised as follows. Other road users become so easily accustomed to automated vehicles being safe that they exploit the vehicle safety and take advantage of it.

This is, if it was needed, a confirmation that infrastructures do need to help interaction. CityMobil2 had already defined infrastructure requirements [1–3] and a certification procedure for infrastructures (alongside

vehicle and supervisory system) [4] and made this approach the basis for its proposal of legal approach [5]. However, these findings demonstrate how infrastructures do not only need to be conceived for safety but also need to be 'constrictive' to force users to behave correctly (if possible).

Naturally, the results obtained here are partial and strongly influenced by the low speed of the CityMobil2 demonstration vehicles and might be reconsidered when speed will be higher. However, absolute safety has this countereffect to consider.

4.1.3 CityMobil2 INTERVIEWS WITH USERS

Interviews and focus groups were made in the three main demonstrators to assess which information to provide and how best to provide them.

According to the surveys with the local VRU in La Rochelle, Lausanne and Trikala, the main information the automated vehicle has to provide to other road users are as follows:

- Whether it is stopping
- Whether it is turning
- How fast it is going
- Whether it is going to start moving
- Whether it has detected me

Detection (somehow replacing the eye contact) is the most important and speed the least.

The best way to receive such information was also tested with the local VRUs. They were asked how they would prefer to receive such information choosing between the following:

- Visual (lights)
- Visual (words)
- Auditory (tones/signals)
- Auditory (words)

Surveys in the three cities give different results as shown in Figs 4.3–4.5, all sourced from Ref. [6].

Overall, the main finding is about the importance of having the vehicle trajectory well indicated on the ground. In CityMobil2, the vehicle route was never painted, but if it were (as imagined in Fig. 4.6), other road users such as pedestrians would have considered safer (Fig. 4.7) and with higher priority (Fig. 4.8) the automated vehicle.

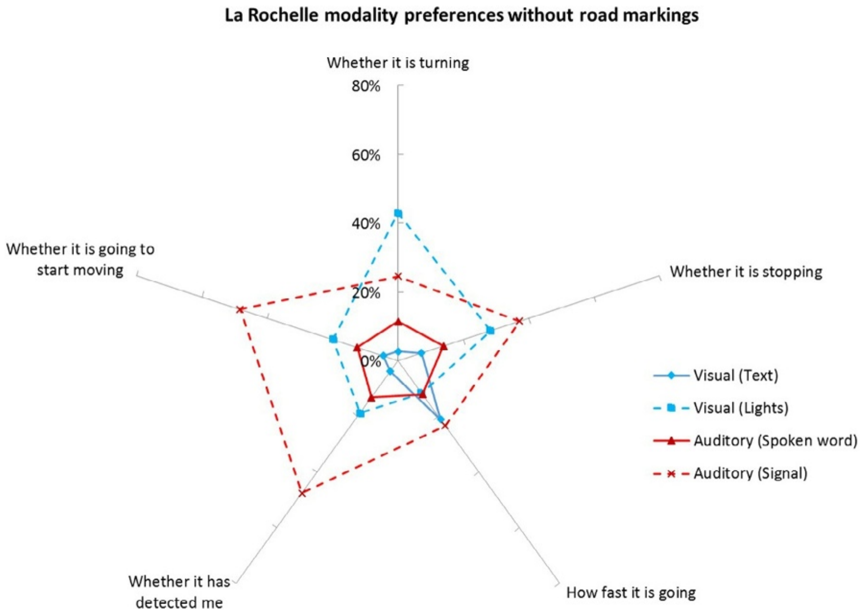

Fig. 4.3 La Rochelle survey results on communicating with the driverless vehicle. *(Source: Natasha Merat's presentation at CityMobil2 final conference in San Sebastian, 2016.)*

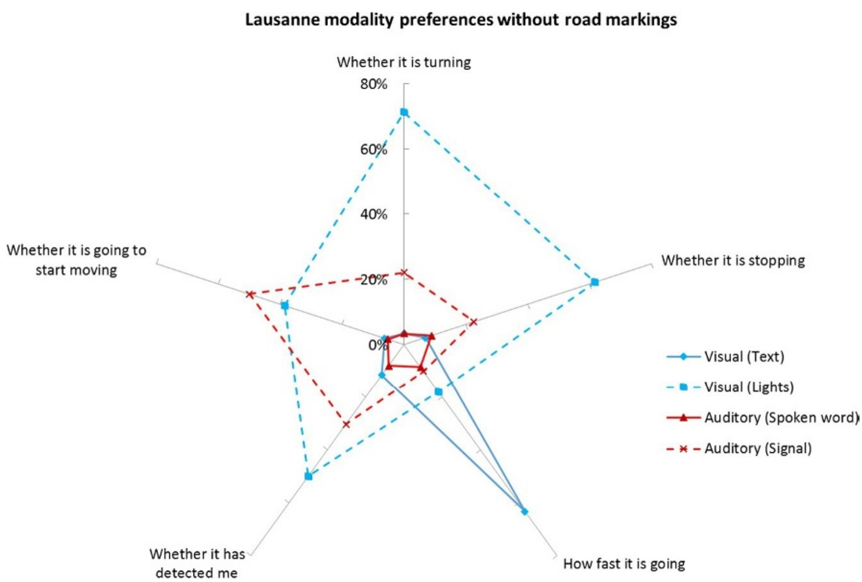

Fig. 4.4 Lausanne survey results on communicating with the driverless vehicle. *(Source: Natasha Merat's presentation at CityMobil2 final conference in San Sebastian, 2016.)*

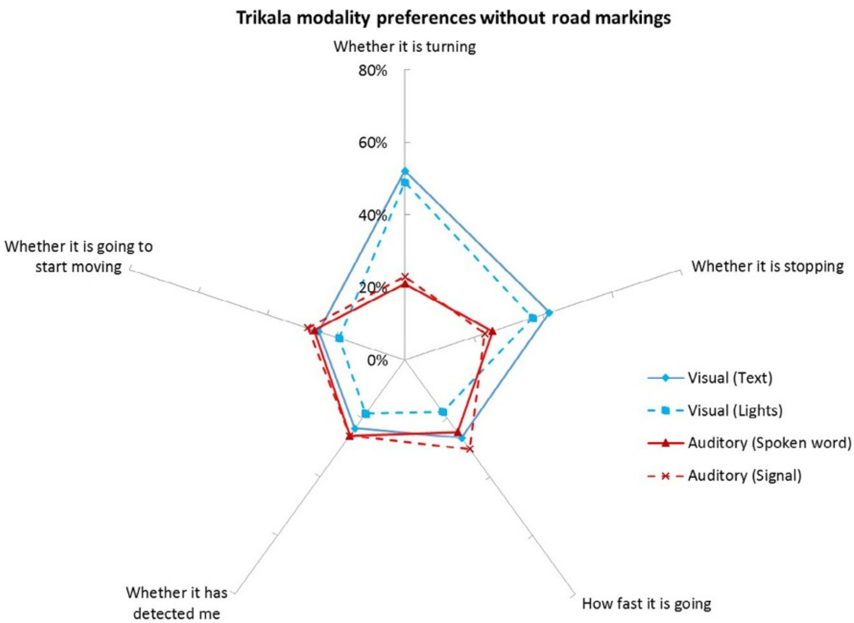

Fig. 4.5 Trikala survey results on communicating with the driverless vehicle. *(Source: Natasha Merat's presentation at CityMobil2 final conference in San Sebastian, 2016.)*

Fig. 4.6 La Rochelle ARTS with and without road markings. *(Source: Natasha Merat's presentation at CityMobil2 final conference in San Sebastian, 2016.)*

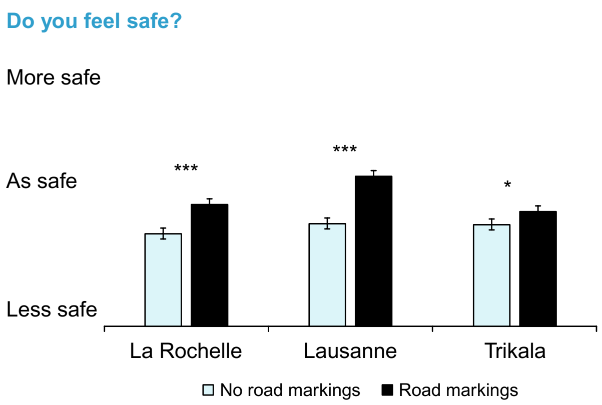

Fig. 4.7 Change in safety perception depending on road markings. *(Source: Natasha Merat's presentation at CityMobil2 final conference in San Sebastian, 2016.)*

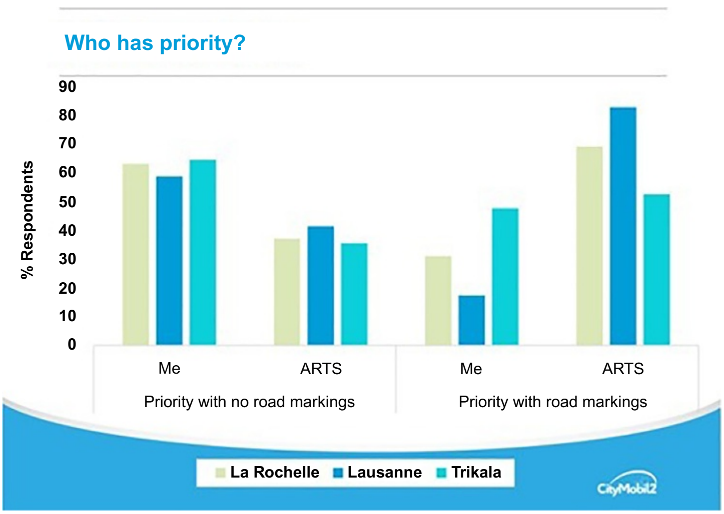

Fig. 4.8 Priority pedestrian versus ARTS without and with road markings. *(Source: Natasha Merat's presentation at CityMobil2 final conference in San Sebastian, 2016.)*

4.1.4 CONCLUSIONS

CityMobil2 being the first project to bring fully automated road transport services on the streets for long-enough durations to have people getting used to them has had the opportunity to investigate how users and other road users react to automated vehicles.

It was done by interviewing people on the field after they had the chance to see (and even try) the ARTS, and it was done by collecting 3-D images of people around the vehicles and assessing people behaviour.

Though CityMobil2 has just scratched the surface of these interesting topics, few conclusions can already be drafted.

First, the infrastructure is more important for VRU than expected. Painting the vehicle path on the street identifying clearly crossings changes the perception of safety and priority.

Second, novelty wears off. People get easily used to the new technology and have even started exploiting its safety.

Overall, the system design will need to take care of these aspects to be fully functional.

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This paper reports the finding of the project coordinator interpreting the work done in that WP.

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CHAPTER 4.2

Assessing Automation Impact on Transport Demand

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4.2.1 INTRODUCTION

Within the CityMobil2 project, 12 cities prepared a proposal for the demonstration of an automated road transport system (ARTS) for different application cases (e.g. providing a link within a major facility such as campus). Based on the evaluation framework developed in the project [1], in each of these cities, a stated preference (SP) survey [2] was carried out (referred to as ex ante survey) to assess users' attitude towards an ARTS and a conventional minibus, using the same questionnaire in all cities. The cities that proposed the most interesting application cases were selected to host the demonstrations: among these cities were La Rochelle (France), Lausanne (Switzerland), Trikala (Greece) and Vantaa (Finland). During the demonstrations, an SP survey involving only ARTS users was carried out (referred to as ex post survey) in each of these four cities to assess users' attitude towards an ARTS and a conventional minibus after having experienced it, using the same questionnaire in all cities. The responses collected ex ante and ex post were used to estimate logit models [3–5]. This chapter reports on the results of the estimations.

4.2.2 METHODOLOGY

4.2.2.1 The Stated Preference (SP) Surveys

The ex ante SP surveys collected data mainly by means of face-to-face interviews and in a few cases online questionnaires. In each city, the sample consisted of potential users of the proposed ARTS service.

The attributes and corresponding levels of the SP design are shown in Table 4.1. The number of combinations in the full factorial design (eight combinations) has been reduced to four combinations using a within-alternative orthogonal design technique.

Also in the ex post SP surveys, data were collected by means of face-to-face interviews and online questionnaires. The sample consisted of actual users of the demonstrated ARTS service. Table 4.2 shows the SP design in this case.

Table 4.1 SP design in the ex ante surveys—attributes and levels

Alternative	Attribute	Number of levels	Levels
Conventional/ automated	Waiting time	2	3/8 min
	Riding time	2	5/10 min
	Fare	2	As other public transport means in the city/extra fare of 2 EUR per return journey (reduced to 1 EUR in La Rochelle)

Table 4.2 SP design in the ex post surveys—attributes and levels

Alternative	Attribute	Number of levels	Levels
Conventional/ automated	Waiting time	2	Perceived waiting time/two times the waiting time in minutes
	Riding time	2	Perceived riding time/0.8 times the riding time in minutes
	Fare	2	As other public transport means in the city/extra fare of 2 EUR per return journey (reduced to 1 EUR in La Rochelle)

4.2.2.2 The Econometric Models

Two alternatives are considered. We denote by 1 the conventional bus alternative and by 2 the ARTS alternative. Let j be the index of alternative. Let $n = 1, \ldots, N$ be the index of individual. Let $t = 1, \ldots, T$ be the index denoting choice task. In the present case, we have $T = 4$.

The utility $u_j^n(t)$ of an alternative is the sum of the systematic component $V_j^n(t)$ and the random term $\epsilon_j^n(t)$:

$$u_j^n(t) = V_j^n(t) + \epsilon_j^n(t) \qquad j = 1, 2; t = 1, \ldots, 4; n = 1, \ldots, N \tag{4.1}$$

The following is the basic specification of systematic utilities:

$$V_1^n(t) = \beta_1 \cdot WT_1^n(t) + \beta_2 \cdot RT_1^n(t) + \beta_3 \cdot FA_1^n(t) \tag{4.2}$$

$$V_2^n(t) = \beta_1 \cdot WT_2^n(t) + \beta_2 \cdot RT_2^n(t) + \beta_3 \cdot FA_2^n(t) + ASC \tag{4.3}$$

where WT is waiting time; RT is riding time; FA is fare; β_1, β_2 and β_3 are the coefficients; and ASC is the alternative-specific constant of

the ARTS alternative. For fare, effect coding (−1/1) was used instead of dummy coding (0/1) to avoid confounding with the ASC. The code −1 represents the case where an extra fare is paid. The code +1 represents the case where the same fare as other public transport is paid.

In the basic specification, the coefficients, which are representative of the marginal utilities of the attributes, are common to the two alternatives. A specification with alternative-specific coefficients has also been tested. Other specifications include socio-economic variables of the users (gender, age, income and education) in the systematic utility of the automated alternative:

$$V_1^n(t) = \beta_1 \cdot WT_1^n(t) + \beta_2 \cdot RT_1^n(t) + \beta_3 \cdot FA_1^n(t) \quad (4.4)$$

$$V_2^n(t) = \beta_1 \cdot WT_2^n(t) + \beta_2 \cdot RT_2^n(t) + \beta_3 \cdot FA_2^n(t) + \beta_{SE} \cdot SE + ASC \quad (4.5)$$

For the socio-economic attributes SE, we make a distinction between two classes. The first is the class of attributes whose levels cannot be attributed with an ordinal meaning: gender (category). The second is the class of attributes whose levels have ordinal meaning, that is, whose levels can be ordered: age (integer number), income (category) and education (category).

For the first class, a dummy variable with effect coding is created. For the second class, it is assumed that the effect is linear. Therefore, for each attribute, a single variable is created. The corresponding integer is assigned to each level if the variable is an integer as in the age case, or if the variable is categorical, the following coding is assigned: 1, 2, …, as in the case of income and education. Levels and coding are shown in Table 4.3.

Table 4.3 Variables and levels used in model specification and estimation

		Levels	Variable	Coding
Gender	Male	1	GEN	+1
	Female	2		−1
Household income	Less than 10,000 EUR/year	1	INC	1
	Between 10,000 and 25,000	2		2
	Between 25,000 and 50,000	3		3
	Between 50,000 and 75,000	4		4
	More than 75,000	5		5
Education	Primary school	1	EDU	1
	Secondary school	2		2
	University first degree	3		3
	PhD	4		4

Of particular interest is the estimation of the *ASC* of the automated alternative, because this represents the mean of all the unobserved attributes that affect the preference: with a common specification of the systematic utilities of the services provided by the two vehicles and the observed attributes being the same, a positive value of the *ASC* is indicative of a relatively higher preference for automation, because of the resulting higher choice probability.

Also of interest is the estimation of the effect on the *ASC* of the socio-economic attributes of the users, because this is indicative of the effect of the socio-economic attribute on the relative preference for automation (e.g. whether preference for the automated alternative increases with age or vice versa).

The distribution of the random terms identifies the discrete choice model. For a given individual and choice task, it is assumed that the random terms are distributed independently and identically across alternatives according to a standard Gumbel distribution. Thus, the difference between the random terms of the two alternatives is distributed according to a logistic distribution, which is denoted by Λ (having omitted the index of individual):

$$F\left(\epsilon_1(t) - \epsilon_2(t) < \eta(t)\right) = \Lambda\left(\eta(t)\right) = \frac{1}{1 + e^{-\eta(t)}} \tag{4.6}$$

This implies that the marginal choice is binomial logit.

In the standard estimation of logit models with SP data, the random terms of each alternative are assumed independent across choice tasks and individuals. The cumulative distribution of the difference of the random terms of a given individual is (having omitted the individual index)

$$F\left(\epsilon_1(t) - \epsilon_2(t) < \eta(t), t = 1, \ldots, T\right) = \prod_{t=1}^{T} \Lambda\left(\eta(t)\right) \tag{4.7}$$

The likelihood function is

$$L = \prod_{n=1}^{N} L^n = \prod_{n=1}^{N} \prod_{t=1}^{T} \frac{e^{\left[V_1^n(t) - V_2^n(t)\right] \cdot d^n(t)}}{1 + e^{\left[V_1^n(t) - V_2^n(t)\right]}} \tag{4.8}$$

where $d^n(t) = 1$ if alternative 1 is chosen and $d^n(t) = 0$ if alternative 2 is chosen.

The decision rule regarding the statistical significance of each coefficient is based on the *t*-statistic: the null hypothesis that the true value of the coefficient is zero can be rejected with 5% significance level if the *t*-statistic

is in absolute value higher than 1.96 and with 10% significance level if the *t*-statistic is in absolute value higher than 1.65. The significance level equals the probability of type 1 error, that is, the error consisting in rejecting the null hypothesis when this is true.

The estimations of logit models that take correlation among repeated observations by the same respondent into account (the error component logit and the copula logit), based on the ex ante SP data, are reported on in two papers by Alessandrini et al. [6,7].

4.2.2.3 Application Cases

It is interesting to assess ARTS performance and users' attitude towards ARTS in different transport applications determined by the specific origin and the destination served. The routes proposed by the 12 cities for the demonstrations (ex ante) fall in the following kinds of application cases (Table 4.4):

- A1—within city centre: La Rochelle (France), Oristano (Italy), Reggio Calabria (Italy) and Trikala (Greece)
- A2—within major facility: CERN (Switzerland), Lausanne (Switzerland), San Sebastian (Spain) and Sophia Antipolis (France)
- A3—from public transport (PT) node to major facility: Brussels (Belgium), León (Spain) and Milan (Italy)
- A4—from PT node to residential area: Vantaa (Finland)

The proposals, which required carrying out feasibility studies with demand assessment and system sizing, included both cases in which segregated lanes were used and cases where mixed-traffic lanes were used. Due to the temporary nature of the demonstrations, the infrastructure interventions were limited to the minimum amount necessary. However, in these proposals, attention was also paid to the needs of the mobility impaired (e.g. the vehicle design provided for unfolding ramps for wheelchairs).

The demonstrations actually implemented in La Rochelle, Lausanne and Trikala were a bit different from the one identified in the proposals, but they still provide the proposed service in the same location (Table 4.5). Vantaa's ARTS demonstration route was again located in the Kivistö area, but instead of providing a service from PT node to a residential area (as planned in the proposal), it actually provided a service from PT node to a major facility: in fact, it provided a link between the Kivistö railway station and the entrance to the Housing Fair 2015.

Table 4.4 The ex ante application cases

Application case		**City**	**Country**	**Route**	**Length (km)**
A1	Within city centre	La Rochelle	France	Link between the main railway station and the university (Technoforum)	2.6
		Oristano	Italy	Link between the seafront of Torre Grande and the touristic port	6
		Reggio Calabria	Italy	Link between the railway central station and the executive administrative centre	4.2
		Trikala	Greece	At the service of the areas of Varussi and Central Square	1.8
A2	Within major facility	CERN	Switzerland	At the service of the main building area and restaurant #2	2
		Lausanne	Switzerland	Link between the north and the south area of the EPFL campus	1.4
		San Sebastian	Spain	Link between the entrance of Miramón Technology Park and the head offices of the different companies inside it	2.1
		Sophia Antipolis	France	Link between the area of Trois-Moulins and the area of Saint-Philippe	3.8
A3	From public transport node to major facility	Brussels	Belgium	Link between the Saint-Luc Hospital and the Kraainem Metro Station	2
		León	Spain	Link between the FEVE train station 'La Asunción' and the university campus	1.5
		Milan	Italy	Link between the 'Molino Dorino' metro station and the south gate of the EXPO 2015 (Milan Universal Exposition)	1.5
A4	From public transport node to residential area	Vantaa	Finland	Link between the Kivistö railway station and the entrance to the Housing Fair 2015	2

Table 4.5 The ex post application cases

Application case		City	Country	Route	Length (km)
A1	Within city centre	La Rochelle	France	Link between the Aquarium (nearby the main railway station) and the university (Technoforum)	3
		Trikala	Greece	Link between the central bus terminal and the area of Varussi	2.9
A2	Within major facility	Lausanne	Switzerland	Link between the north and the south area of the EPFL campus	1.5
A3	From public transport node to residential area	Vantaa	Finland	Link between the Kivistö railway station and the entrance to the Housing Fair 2015	1

4.2.3 ESTIMATION RESULTS

4.2.3.1 Econometric Analysis

Tables 4.6 and 4.7 show the calibration results of the basic econometric model of the ex ante (12 cities) and ex post (4 cities) surveys, respectively.

All attribute coefficients estimated ex ante show the right sign: negative for waiting and riding time, which implies a lower user's utility as they increase, and positive for extra fare having used the 'effect coding' −1/1 (respectively when an extra fare or the same fare as other PT means is charged to users of the ARTS).

The ex ante estimations produced not statistically significant (two-tailed *t*-test with 'attribute coefficient = 0' as null hypothesis and 10% significance level) attribute coefficients only in six cases: waiting time coefficient in La Rochelle and León, riding time coefficient in Vantaa, extra-fare coefficient in León and *ASC* in Sophia Antipolis and Trikala.

The ex ante results show that the *ASC* is positive in 6 out of 10 cities (excluding Sophia Antipolis and Trikala, because their *ASC* are not statistically significant). However, in all cities (excluding Sophia Antipolis, because

Table 4.6 Ex ante surveys—calibration results of the basic econometric models

		A1				A2				A3			A4
Attribute	**Parameter**	**La Rochelle (FR)**	**Oristano (IT)**	**Reggio Calabria (IT)**	**Trikala (GR)**	**CERN (CH)**	**Lausanne (CH)**	**San Sebastian (ES)**	**Sophia Antipolis (FR)**	**Brussels (BE)**	**León (ES)**	**Milan (IT)**	**Vantaa (FI)**
Waiting time	Coefficient	−0.0453	−0.3205	−0.1925	−0.0960	−0.3829	−0.3778	−0.2003	−0.3132	−0.2095	−0.0372	−0.2390	−0.1563
	t-Statistics	−1.11	−6.22	−3.58	−2.28	−13.24	−15.22	−4.39	−8.42	−4.92	−0.53	−5.30	−2.18
Riding time	Coefficient	−0.0564	−0.2910	−0.2472	−0.0872	−0.3482	−0.3976	−0.2078	−0.2808	−0.1989	−0.2414	−0.1936	−0.0068
	t-Statistics	−1.95	−8.67	−6.89	3.02	−17.28	−23.18	−6.72	−10.75	−6.45	−4.83	−6.35	−0.14
Extra fare	Coefficient	0.5055	1.5697	0.7838	0.4683	0.9945	0.5540	0.8358	0.7321	0.4973	0.3545	1.1117	0.4518
	t-Statistics	4.03	9.08	4.41	3.57	11.62	8.19	5.69	6.08	3.64	1.60	7.64	1.89
ASC (ARTS)	Coefficient	0.5636	1.1935	−0.4747	−0.0136	1.2233	0.8641	0.2853	0.1620	−0.2753	−1.8703	0.8680	−1.5684
	t-Statistics	3.90	7.11	−2.65	−0.09	12.14	10.07	1.85	1.24	−1.85	−7.48	5.69	−6.34
Sample size		200	200	209	208	482	742	200	290	201	227	200	167

A1, within city centre; A2, within major facility; A3, from PT node to major facility; A4, from PT node to residential area.
Statistical significance (10% confidence level): t-stat > 1, 65.

Table 4.7 Ex post surveys—calibration results of the basic econometric models

		A1		A2	A3
Attribute	**Parameter**	**La Rochelle (FR)**	**Trikala (GR)**	**Lausanne (CH)**	**Vantaa (FI)**
Waiting time	Coefficient	–	−0.041	–	−0.770
	t-Statistics	–	−1.31	–	−15.44
Riding time	Coefficient	0.082	–	0.095	−0.228
	t-Statistics	1.21	–	1.26	−1.98
	Minibus coefficient	–	0.086	–	–
	t-Statistics	–	1.50	–	–
	ARTS coefficient	–	0.170	–	–
	t-Statistics	–	3.10	–	–
Extra fare	Coefficient	0.682	0.613	1.174	0.375
	t-Statistics	6.74	7.9	10.55	4.01
ASC (ARTS)	Coefficient	0.539	−0.278	1.291	−0.827
	t-Statistics	3.13	−1.15	7.32	−4.51
Sample size		110	200	114	212

A1, within city centre; A2, within major facility; A3, from public transport node to major facility.
The city in bold character hosted a large-scale demonstration.
Statistical significance (10% confidence level): *t*-stat > 1.65.

its *ASC* is not statistically significant, even though positive) that planned to implement the service within a major facility, there is a relatively higher preference for the ARTS.

The ex post estimations produced not statistically significant (two-tailed *t*-test with 'attribute coefficient = 0' as null hypothesis and 10% significance level) attribute coefficients in four cases: waiting time coefficient in Trikala, riding time coefficient in La Rochelle and Lausanne and *ASC* in Trikala.

The extra-fare coefficients estimated ex post correctly show a positive sign in all cities. The waiting time coefficients show a negative sign as expected, even though for La Rochelle and Lausanne (the two cities with significantly smaller sample sizes) it was possible to calibrate the econometric model only by removing the waiting time attribute. The riding time coefficients unexpectedly show a positive sign: this might be explained by the fact that ARTS users in those cities show a relatively higher preference for the ARTS (as their *ASC* positive sign suggests, except for Trikala, in which the *ASC*, however, is not statistically significant), and consequently, they might enjoy a longer journey onboard the ARTS.

The *ASC* in Vantaa estimated ex post is negative as in the ex ante estimation, and therefore, users show a relatively higher preference for the conventional minibus regardless whether or not they experienced the ARTS.

Tables 4.8 and 4.9 show, for the city of La Rochelle, Trikala, Lausanne and Vantaa, respectively, the ex ante and ex post calibration results of the models whose specification includes as additional attribute, one at a time, gender, age and level of education.

The ex ante calculations were performed for all the 12 cities and included other socio-economic characteristics (income, occupation, car availability and ownership of PT monthly ticket), but are not shown here (they are found in Ref. [8]). The general ex ante result is that the impact of these socio-economic attributes varies city by city and in many cases is not statistically significant. However, in eight out of the nine cities (in particular in all cities that planned to implement the service within a major facility), in which the gender attribute is statistically significant (two-tailed *t*-test with 'attribute coefficient = 0' as null hypothesis and 10% significance level), being male increases ARTS user's utility (enhancing the relatively higher preference for the ARTS), while being female decreases it. Furthermore, the level of education coefficient is statistically significant in all four cities that planned to implement the service within the city, and in three out of four of these, having a higher education level increases user's preference for the ARTS.

Table 4.8 Ex ante surveys—calibration results of the basic econometric model including one socio-economic characteristic (gender, age and education)

		Gender				Age				Education			
		A1		A2	A4	A1		A2	A4	A1		A2	A4
Attribute	**Parameter**	**La Rochelle (FR)**	**Trikala (GR)**	**Lausanne (CH)**	**Vantaa (FI)**	**La Rochelle (FR)**	**Trikala (GR)**	**Lausanne (CH)**	**Vantaa (FI)**	**La Rochelle (FR)**	**Trikala (GR)**	**Lausanne (CH)**	**Vantaa (FI)**
Waiting time	Coefficient	−0.0453	−0.0996	−0.3830	−0.1567	−0.0454	−0.0976	−0.3780	−0.1570	−0.0455	−0.0979	−0.3784	−0.1563
	t-Statistics	−1.11	−2.33	−15.30	−2.18	−1.12	−2.30	−15.22	−2.18	−1.12	−2.30	−15.23	−2.18
Riding time	Coefficient	−0.0564	−0.0907	−0.4031	−0.0068	−0.0565	−0.0888	−0.3978	−0.0068	−0.0567	−0.0890	−0.3983	−0.0068
	t-Statistics	−1.95	−3.07	−23.22	−0.14	−1.95	−3.04	−23.18	−0.14	−1.95	−3.04	−23.18	−0.14
Extra fare	Coefficient	0.5055	0.4863	0.5622	0.4532	0.5070	0.4763	0.5542	0.4538	0.5085	0.4775	0.5549	0.4519
	t-Statistics	4.03	3.64	8.25	1.90	4.04	3.60	8.19	1.90	4.04	3.61	8.20	1.89
ASC (ARTS)	Coefficient	0.5614	−0.0154	0.7713	−1.5777	0.2631	0.7490	0.7465	−2.3322	0.2002	−1.0300	1.1267	−1.7167
	t-Statistics	3.88	−0.10	8.83	−6.35	1.08	3.01	5.56	−4.59	0.90	−3.52	7.39	−3.72
Socio-economic variable	Coefficient	−0.0195	0.4122	0.2694	0.1773	0.0897	−0.0209	0.0042	0.0173	0.1772	0.3766	−0.0857	0.0490
	t-Statistics	−0.27	5.57	5.88	1.48	1.52	−3.77	1.13	1.75	2.15	4.00	−2.10	0.38
Sample size		200	208	742	167	200	208	742	167	200	208	742	167

A1, within city centre; A2, within major facility; A4, from PT node to residential area.
Statistical significance (10% confidence level): *t*-stat > 1.65.

Table 4.9 Ex post surveys—calibration results of the basic econometric model including one socio-economic characteristic (gender, age and education)

		A1		A2	A3
Attribute	**Parameter**	**La Rochelle (FR)**	**Trikala (GR)**	**Lausanne (CH)**	**Vantaa (FI)**
Gender	Coefficient	−0.143	−0.246	–	−0.279
	t-Statistics	−1.40	−3.17	–	−1.50
Age	Coefficient	0.011	−0.005	–	−0.011
	t-Statistics	1.91	−0.95	–	−0.26
Education	Coefficient	−0.125	0.547	–	−0.087
	t-Statistics	−1.92	6.85	–	−1.20
Sample size		110	200	114	212

A1, within city centre; A2, within major facility; A3, from public transport node to major facility.
The city in bold character hosted a large-scale demonstration.
Statistical significance (10% confidence level): *t*-stat > 1.65.

In the cities involved in the ex post SP survey, only gender, age and level of education were added to the specifications of the ARTS utility of the basic model. The calibration of the model with these socio-economic variables failed in Lausanne, while in Vantaa, none of the socio-economic attributes was statistically significant.

In La Rochelle, the age coefficient was statistically significant (differently from the ex ante result) and positive, that is, being older increases user preference for the ARTS. The level of education coefficient in La Rochelle was statistically significant and negative, implying that having a lower education level increases user's preference for the ARTS; this result is the opposite of that found in the ex ante survey. A possible explanation for this result might be that people with lower levels of education had insufficient familiarity with the notion of automation and its actual feasibility before experiencing the ARTS service. Once they experienced it, they realised the advantages of the ARTS. On the other hand, the low service speed due to safety reasons resulted in a level of service that did not live up to the expectations of people with higher level of education.

The gender coefficient in Trikala was positive in the ex ante calibration and negative in the ex post calibration. As for the level of education coefficient in Trikala, the ex post results are the same as the ex ante one: having higher level of education increases user's preference for the ARTS.

The ex ante econometric analysis showed that time and fare alternative-specific coefficients are not statistically significant, except for riding time in Brussels, implying that in all cities except for Brussels, the marginal disutility of total travel time (and in particular on-board time) is the same using both ARTS and minibus. As we have seen before, the ex post estimation of the econometric model showed that in Trikala, there is an alternative-specific marginal utility associated with on-board time that is statistically significant only for the ARTS.

Finally, an assessment of the impact of extra fare on ARTS and minibus share preference was performed using the ex post calibrated econometric model. The values of the attributes waiting time and riding time of the utility function used to calculate the alternative shares have been set by each city on the basis of the specific operational characteristics of the service demonstrated. The results are that the ARTS share was significantly reduced in all cities when ARTS users are charged an extra fare (Table 4.10): the percentage reduction of the ARTS shares varied from a minimum of 35% in Trikala, to 43% in Vantaa and 52% in La Rochelle, to a maximum of 67%

Table 4.10 Ex post estimations—impact of ARTS extra fare on the ARTS and minibus preference shares

		Preference shares				Utility function parameters		
		No extra fare		Extra fare		Attribute		
		ARTS	Minibus	ARTS	Minibus	Coefficients	No extra-fare scenario	Extra-fare scenario
A1	La Rochelle (FR)	63%	37%	30%	70%	$\beta_1=\beta_2=0$ $\beta_3=0.682$ $ASC=0.539$	$WT_1=WT_2=10$ $RT_1=RT_2=10$ $FA_1=FA_2=1$	$WT_1=WT_2=10$ $RT_1=RT_2=10$ $FA_1=1, FA_2=-1$
	Trikala (GR)	78%	22%	51%	49%	$\beta_1=\beta_{2\text{Minibus}}=0$ $\beta_{2ARTS}=0.17$ $\beta_3=0.613$ $ASC=0$	$WT_1=WT_2=10$ $RT_1=RT_2=7.5$ $FA_1=FA_2=1$	$WT_1=WT_2=10$ $RT_1=RT_2=7.5$ $FA_1=1, FA_2=-1$
A2	Lausanne (CH)	78%	22%	26%	74%	$\beta_1=\text{NA}$ $\beta_2=0$ $\beta_3=1.174$ $ASC=1.291$	$WT_1=WT_2=\text{NA}$ $RT_1=RT_2=7.5$ $FA_1=FA_2=1$	$WT_1=WT_2=\text{NA}$ $RT_1=RT_2=7.5$ $FA_1=1, FA_2=-1$
A3	Vantaa (FI)	30%	70%	17%	83%	$\beta_1=-0.770$ $\beta_2=-0.228$ $\beta_3=0.375$ $ASC=-0.827$	$WT_1=WT_2=7.5$ $RT_1=RT_2=7.5$ $FA_1=FA_2=1$	$WT_1=WT_2=7.5$ $RT_1=RT_2=7.5$ $FA_1=1, FA_2=-1$

in Lausanne. These results are consistent with the fact that in all cities, only a very low percentage of users were willing to pay more than the current PT fare.

4.2.3.2 Comparison With Previous Studies

There are in literature two previous studies that used the same methodology adopted here (logit models estimated using SP data): [9,10].

Shires and Ibañez investigated the relative preference between an ARTS and a conventional bus service running on an existing PT route in the city of Leeds (the United Kingdom). They found that users showed a relatively higher preference for the conventional bus service. The two authors explained this result as an inbuilt bias due to a more-positive users' attitude towards the currently used transport mode (the PT service actually existed and used conventional buses). The application cases investigated most similar to the one studied by Ref. [9] are La Rochelle, Oristano, Reggio Calabria and Trikala in the ex ante surveys and La Rochelle and Trikala in the ex post survey. The PT services planned in La Rochelle and Oristano did not currently exist, while in Reggio Calabria, it already existed (both ex ante and ex post, the Trikala *ASC* coefficient was not statistically significant and therefore was not included in this discussion). In Reggio Calabria, users showed a relatively higher preference for the minibus while in La Rochelle and Oristano for the ARTS. These results might substantiate [9] assumption; in fact, where the service was already existent (Reggio Calabria), users' preferences might have been biased by their positive attitude towards the currently used conventional transport mode; where the service did not currently exist, users showed a relatively higher preference for the ARTS.

Delle Site et al. [10] examined the relative preference between a minibus and an ARTS short-distance service providing a link between an entrance to the new trade fair district in Rome (Italy) and a nearby parking area. They found a relatively higher preference for the ARTS as the present study found in all cities proposing similar applications: 'within major facility' services (CERN, Lausanne, San Sebastian and Sophia Antipolis) and the service providing a link between a metro station and the entrance to the Milan Universal Exposition (Milan).

4.2.4 CONCLUSION

This study contributed to enhance the knowledge of users' attitudes towards automation in collective road transport systems.

The ex ante cases studied here (except one city) referred to entirely new PT services (i.e. on routes where no PT service did actually exist). The results show that users' attitudes towards ARTS were not uniform across cities and applications cases, except when ARTS are used to provide services within major facilities, a case in which users showed a relatively higher preference for ARTS in all cities. The ex ante results have in general confirmed those of the previous studies: the possible existence of an inbuilt bias due to a more-positive users' attitude towards the currently used transport mode [9] and a relatively higher preference for ARTS for 'within major facility' services [10].

The ex ante results stem from surveying users who had no experience of ARTS and were little informed about it (information given mostly by the interviewer). Information, experience and emotions are key factors for users' preference formation according to the standard behavioural choice model [11]. The CityMobil2 project allowed the authors to collect information on users' attitude towards ARTS after having experienced it in four European cities, which participated also in the ex ante survey. The ex post SP survey results confirmed the ex ante results: a relatively higher preference for the ARTS in La Rochelle and Lausanne and for conventional minibus in Vantaa (Trikala's *ASC* was not statistically significant both ex ante and ex post).

The analysis of the impacts on preferences of users' socio-economic characteristics led to no result common to all cities either ex ante or ex post. Future research might provide further insights into such impacts. The econometric models calibrated in this study can be used to estimate shifts in preferences when the value of the utility function attributes are changed. For example, the ex post SP calibrated models were used to assess the impact of extra fare on the ARTS and minibus preference shares. It was found that the ARTS share was significantly reduced in all cities when an extra fare is applied.

ACKNOWLEDGEMENTS

The survey activities were carried out by the partners of the CityMobil2 project involved in the 12 cities of the feasibility studies and in 4 cities that hosted a demonstration (La Rochelle, Lausanne, Trikala and Vantaa).

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CHAPTER 4.3

User Acceptance and Socio-Economic Evaluation

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4.3.1 INTRODUCTION

The evaluation of the user acceptance towards the ARTS and the socio-economic factor effects on it is reported in this paper, based on the CityMobil2 evaluation framework [1] and following the assessment of automation impacts on transport demand [2].

The user acceptance included both acceptance and quality of service indicator evaluations, whereas the socio-economic factors regarded gender, age, level of education and employment status of the users, as reported in Ref. [3].

This paper is made of four sections.

In this section, the objectives, the methods used and the cities involved in such evaluation are reported and explained.

In Section 4.3.2, the evaluation of the user acceptance in the demonstrations is reported in detail.

Section 4.3.3 reports the links, which were found, between the indicators reported in Section 4.3.2 and the socio-economic factors.

Section 4.3.4 summarises the main results of the user acceptance and the socio-economic evaluation.

4.3.2 OBJECTIVES OF THE EVALUATION

The ex post user evaluation is aimed at the following:

- Collecting information on users' mobility behaviour and their level of satisfaction with the ARTS service and their socio-economic characteristics
- Providing system designers with recommendations for improvement of system characteristics
- Assessing users' perception of safety, security and emergency management and their willingness to pay and assessing whether experience and, depending on the awareness campaign carried out, information alter attitudes towards ARTS

4.3.3 METHODS USED FOR THE EVALUATION

The objectives were pursued by carrying out two separate surveys with ARTS users responding to the following two structured questionnaires:

- Ex post evaluation questionnaire for users. The first survey was specifically designed to collect information on the ARTS users' mobility behaviour and their level of satisfaction with the system.
- Ex post stated preference questionnaire for users. The second survey was designed to collect information on possible changes in attitudes towards the ARTS due to having experienced the system and being informed by awareness raising campaigns and to collect information on users' willingness to pay and their perception of safety, security and emergency management on board the ARTS.

A sample of at least 200 respondents was requested for the questionnaires for each city involved in the evaluation.

4.3.4 CITIES INVOLVED IN THE EVALUATION

The cities of Lausanne (large demo), La Rochelle (large demo), Trikala (large demo), Vantaa (small segregated demo) and Oristano (small demo) provided the data for the evaluations reported in this section. For each city, a sample of at least 200 respondents was requested for the questionnaires.

4.3.5 USER ACCEPTANCE EVALUATION OF THE CityMobil2 DEMONSTRATIONS

Users' satisfaction was assessed using indicators belonging to the following two evaluation categories: user acceptance and quality of service.

User acceptance included the following indicators:

- Usefulness
- Integration with other systems
- Level of service
- Willingness to pay

Quality of service included the following indicators:

- Comfort
- Information provision (availability)
- Perception of safety in terms of accident risk
- Perception of security in terms of fear of attack
- Perception of emergency management

The terms used for some of these indicators (viz. level of service, comfort and information provision) were too general. Consequently, it was decided to break them down into a number of microfactors, which helped to understand the effects in a more precise way. Therefore:

- The indicator level of service was broken down to the following microfactors:
  - On-board time (time spent by users on board)
  - Waiting time at stops (waiting time spent by users at stops)
  - Frequency of decelerations (frequency of decelerations/number of times the vehicle has stopped in addition to stops and traffic lights)
- The indicator for comfort was broken down to the following microfactors:
  - Jerk
  - Seat found
  - Crowding
  - Temperature on board
  - Clear views out
- The indicator information provision was broken down to the following microfactors:
  - Pretrip information availability
  - Information availability at stops
  - Information availability on board

On-board time and waiting time (level of service) are directly linked to the indicator 'reliability'.

The results of the rating of user acceptance indicators and quality of service indicators are discussed in Sections 4.3.5.1 and 4.3.5.2, respectively.

The cities of Lausanne, Oristano, Trikala and Vantaa collected information on both the user level of satisfaction and the importance of each microfactors. The combination of users' rating of the level of satisfaction and importance provides indications improving the ARTS service and vehicle design. To this aim, the conventional factor mapping analysis was used in a plane satisfaction/importance, and the results are presented in Section 4.3.5.3.

4.3.5.1 User Acceptance Indicators and Willingness to Pay

The results relating to user acceptance of the ARTS service were in general positive in all cities (Fig. 4.9) with average ratings above mean values (between indifferent and good).

Fig. 4.10 shows the distribution of ratings over the satisfaction level scale, and almost in all cities, the highest percentages are in correspondence of the level 'good'.

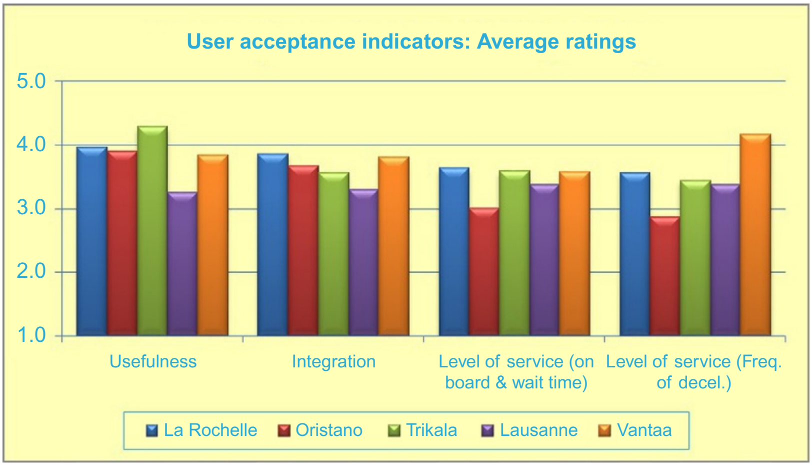

Fig. 4.9 Users: user acceptance indicators—average ratings.

Usefulness of the service obtained the highest ratings in all cities (except for Lausanne, in which the average values of all indicators were more or less the same), in spite of the fact that in all cities, more than 50 % of users declared that it would be better to implement the ARTS service in the future in other routes in other parts of the city, and the level of integration with other transport modes obtained good ratings in all cities.

The level of service indicators (on-board time, waiting time at stops and frequency of decelerations/number of times the vehicle has stopped in addition to stops and traffic lights) was lower in Oristano compared with the other cities. This might be explained as Oristano was a sort of pilot demonstration to test the operation of the automated vehicles and fine-tune their functions. This resulted in a very low (commercial) speed of the vehicles and many incidents and malfunctions.

In contrast, in Vantaa, the frequency of deceleration was given a high rating, as in that demo, the ARTS vehicles operated as shuttle between two terminal stations in a segregated route with no intermediate stops or decelerations.

Fig. 4.11 shows that in all cities, only a low percentage of users were willing to pay more than the current public transport fare. However, most were willing to pay at least as much.

For some cities, it was possible to collect more quantitative information on willingness to pay on top of the current PT fare. The result was that most of the users (who were willing to pay more) were willing to pay just 0.50 EUR more (Fig. 4.12).

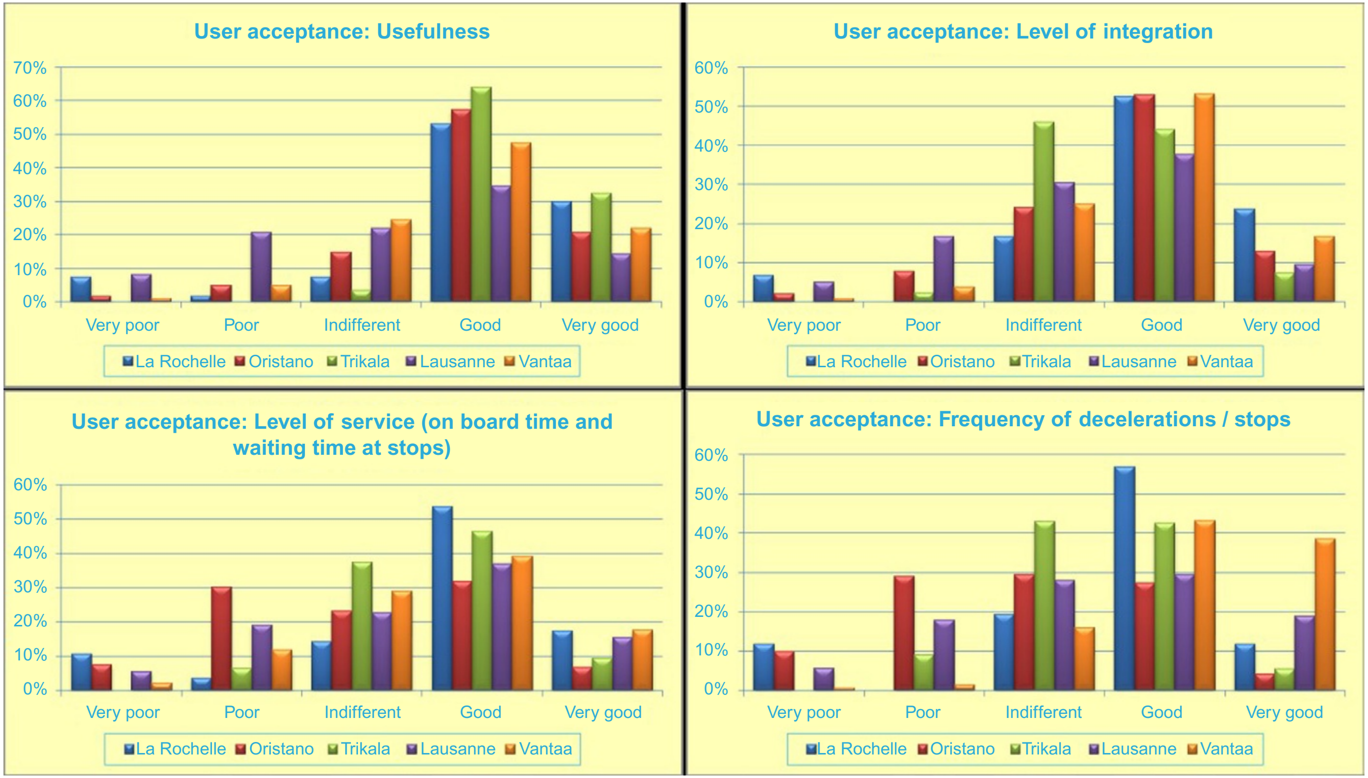

Fig. 4.10 Users: rating of user acceptance indicators.

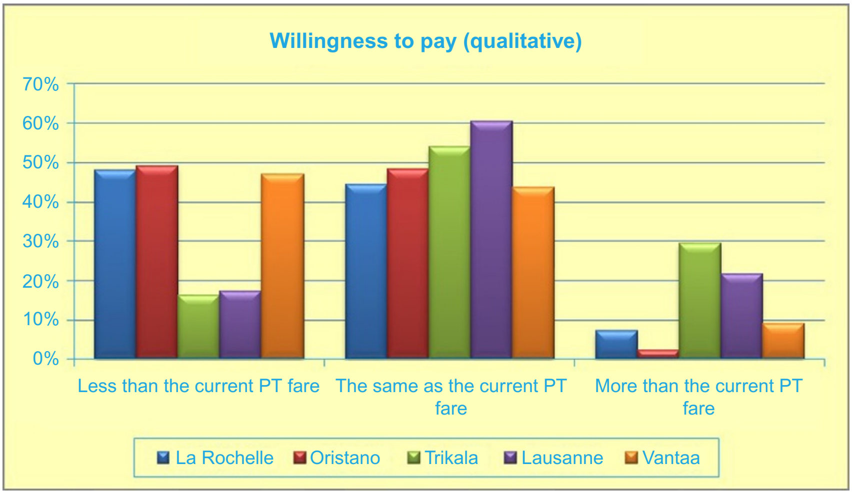

Fig. 4.11 Users: willingness to pay compared with the current PT fare—qualitative assessment.

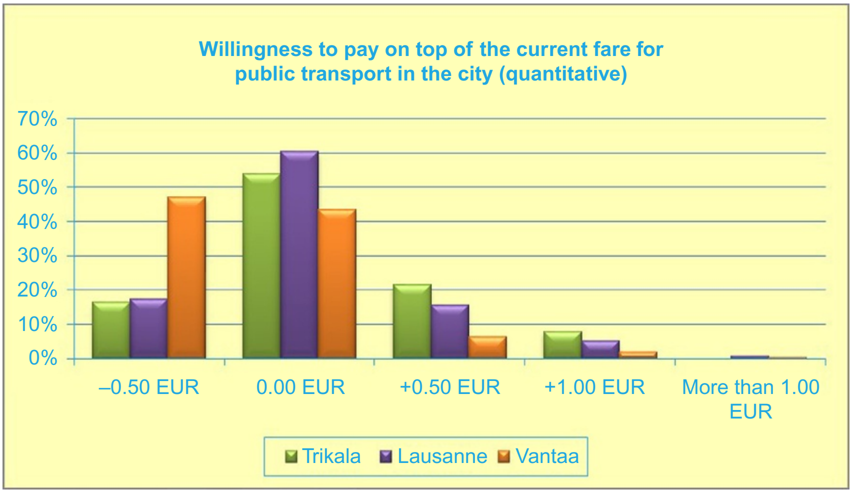

Fig. 4.12 Users: willingness to pay compared with the current PT fare—quantitative assessment.

4.3.5.2 Quality of Service Indicators

The results relating to the average rating of quality of service indicators were above the mean value in all cities as far as comfort, jerk (except for Oristano but this as already said might be due to the pilot character of that demonstration), information availability and perception of safety (in terms of accident risk) are concerned (Fig. 4.13).

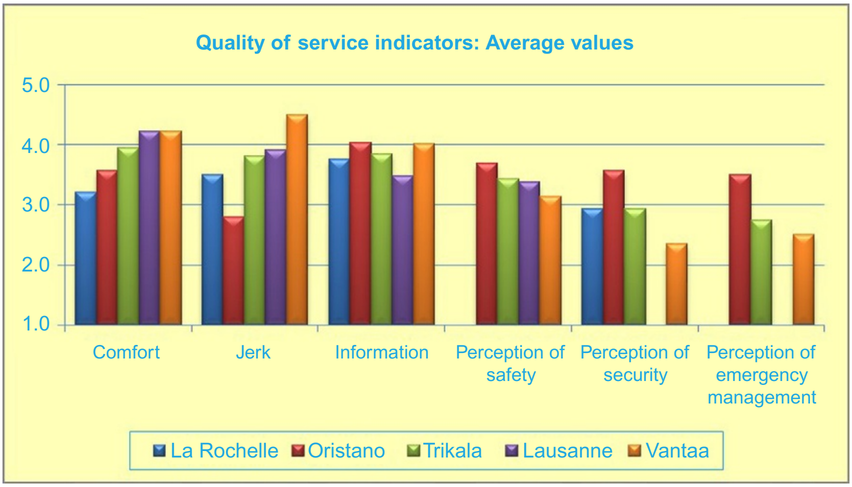

Fig. 4.13 Users: quality of service indicators—average values.

User perception of security (in terms of fear of attack) and user perception of emergency management were rated below the mean value in all cities except for Oristano (this result is bias as the service operating staff inside the vehicle was easily recognisable and this might have induced people to be more confident): this means that people still need the presence of a member of the service operating staff to feel secure from attack and in case of emergency situations.

Fig. 4.14 shows the distribution of ratings of the quality of service indicators over the satisfaction level scale.

4.3.5.3 Factor Mapping Analysis

Information on users' level of satisfaction and the relative importance assigned by users to usefulness, level of integration, level of service, comfort and information provision indicators and their microfactors have been collected in the cities of Lausanne, Oristano, San Sebastian and Vantaa. This information enables to perform a factor mapping analysis, which helps to prioritise the critical factors whose improvement has a major impact in the overall perception of satisfaction.

Fig. 4.15 summarises the results of this analysis for the five indicators at the aggregated level (i.e. the microfactors do not appear). In all cities, the level of satisfaction is equal or above the average for all indicators in all cities; in Vantaa, they were rated higher than in the other cities, and their ratings were more or less equal and approximately equal to 4. The figure also shows that the importance given by users to the satisfaction indicators is more or less the same in Oristano and Vantaa, while it is more dispersed in

the case of Lausanne, which rated usefulness and level of integration more important and comfort less important.

These results show that the indicators whose improvement can better increase the overall level of satisfaction are in order of decreasing importance:

- Level of service, comfort and level of integration in Oristano
- Usefulness, level of integration, level of service and information provision in Lausanne
- Usefulness, level of integration and level of service in Vantaa

The indicators common to all cities are the level of integration and the level of service. Comfort received the highest ratings in Lausanne and Vantaa, and this can be explained by the fact that in Oristano different vehicles (provided by Robosoft) were used from the ones used in Vantaa and Lausanne (provided by EasyMile); usefulness was in Lausanne and Vantaa among the lower-rated indicators in terms of satisfaction and the higher rated in terms of importance.

Therefore, in order to increase the overall level of satisfaction of the ARTS service, designers should focus on choosing more appropriate place/route for the ARTS service paying attention to provide adequate integration between the ARTS and the other transport modes.

Designers should also improve the level of service. A level of service microfactor analysis was used to help identify the microfactors whose improvement can better improve satisfaction with the level of service.

Fig. 4.16 shows that in all cities, the ranking of the microfactors by importance is the same: waiting time at stops is the most important and the frequency of decelerations the less important. Therefore, designers should mainly focus on improving waiting time at stops and on-board time to increase users' level of satisfaction with the level of service indicator.

4.3.6 EFFECTS OF SOCIO-ECONOMIC CHARACTERISTICS ON SOME USER EVALUATION SURVEY INDICATORS

4.3.6.1 User Acceptance Indicators and Willingness to Pay

The analysis of the effects of socio-economic variables (gender, age, level of education and employment status) on the results showed no common patterns in all cities except for gender (Figs 4.17–4.20). For all the four user acceptance indicators, females always rated, on average, the indicators higher than males in all cities except for Oristano in the case of level of integration and Vantaa in the case of frequency of decelerations.

For what concerns the willingness to pay, the analysis of the effects of socio-economic variables (gender, age, level of education and employment status) on the results showed no common patterns for all cities, as reported in Figs 4.21–4.24.

Fig. 4.14 Users: rating of quality of service indicators.

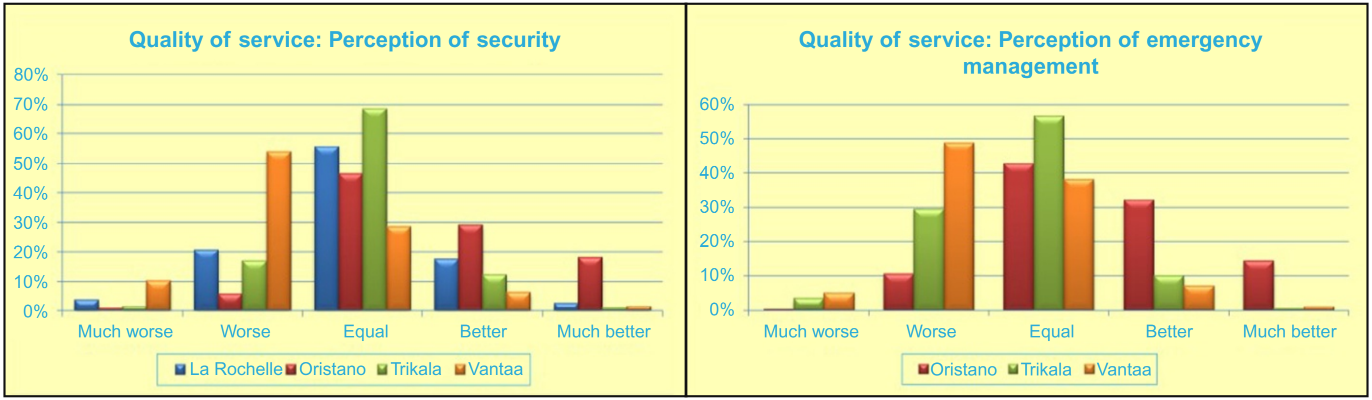

Fig. 4.14 Cont'd

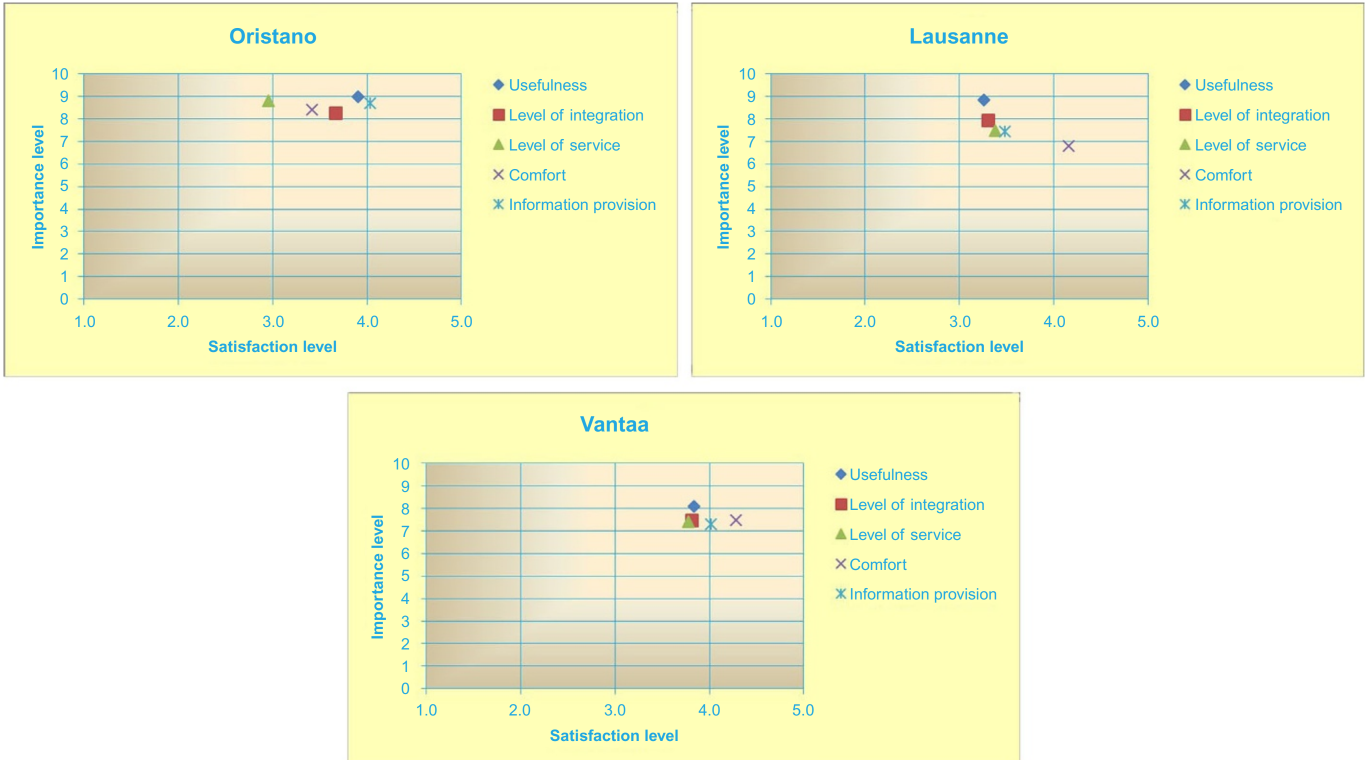

Fig. 4.15 Users: satisfaction factor mapping analysis.

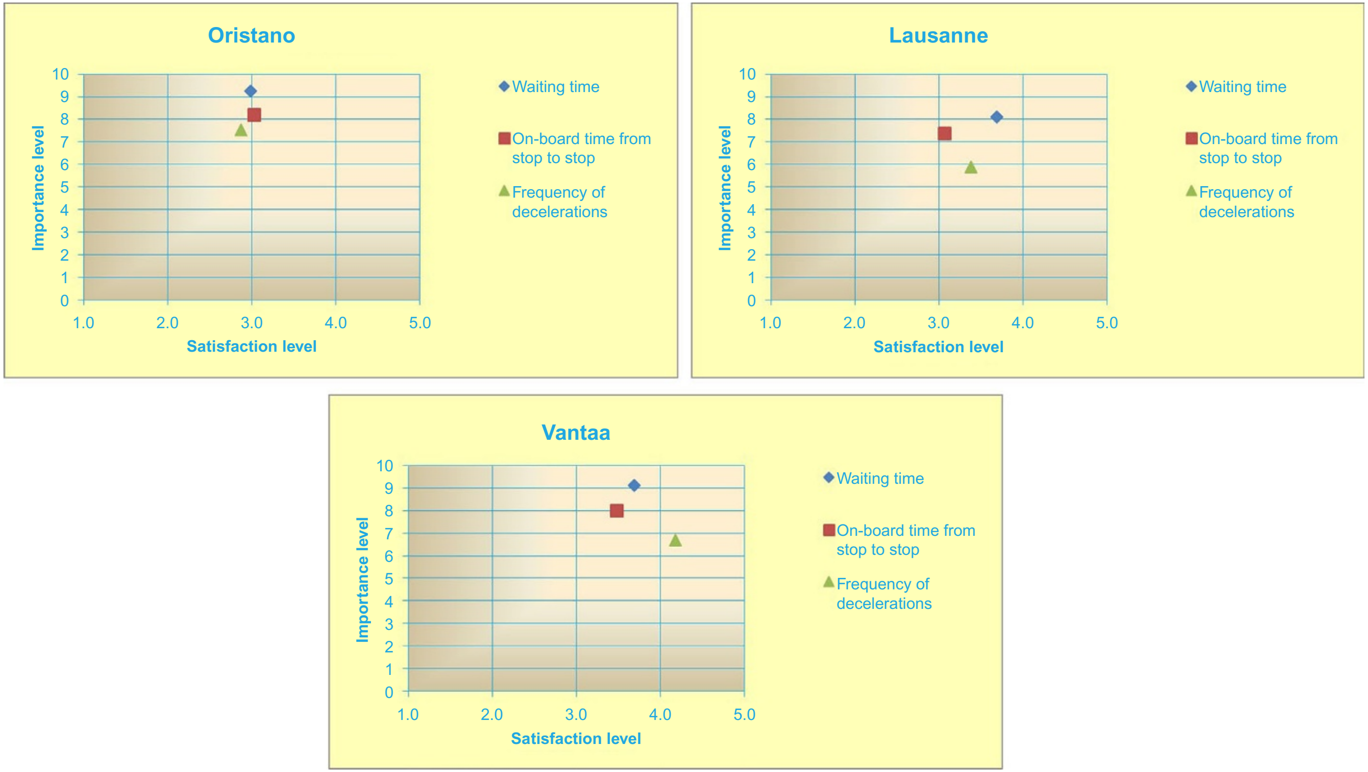

Fig. 4.16 Users: level of service satisfaction microfactor mapping analysis.

Fig. 4.17 User acceptance indicators and gender.

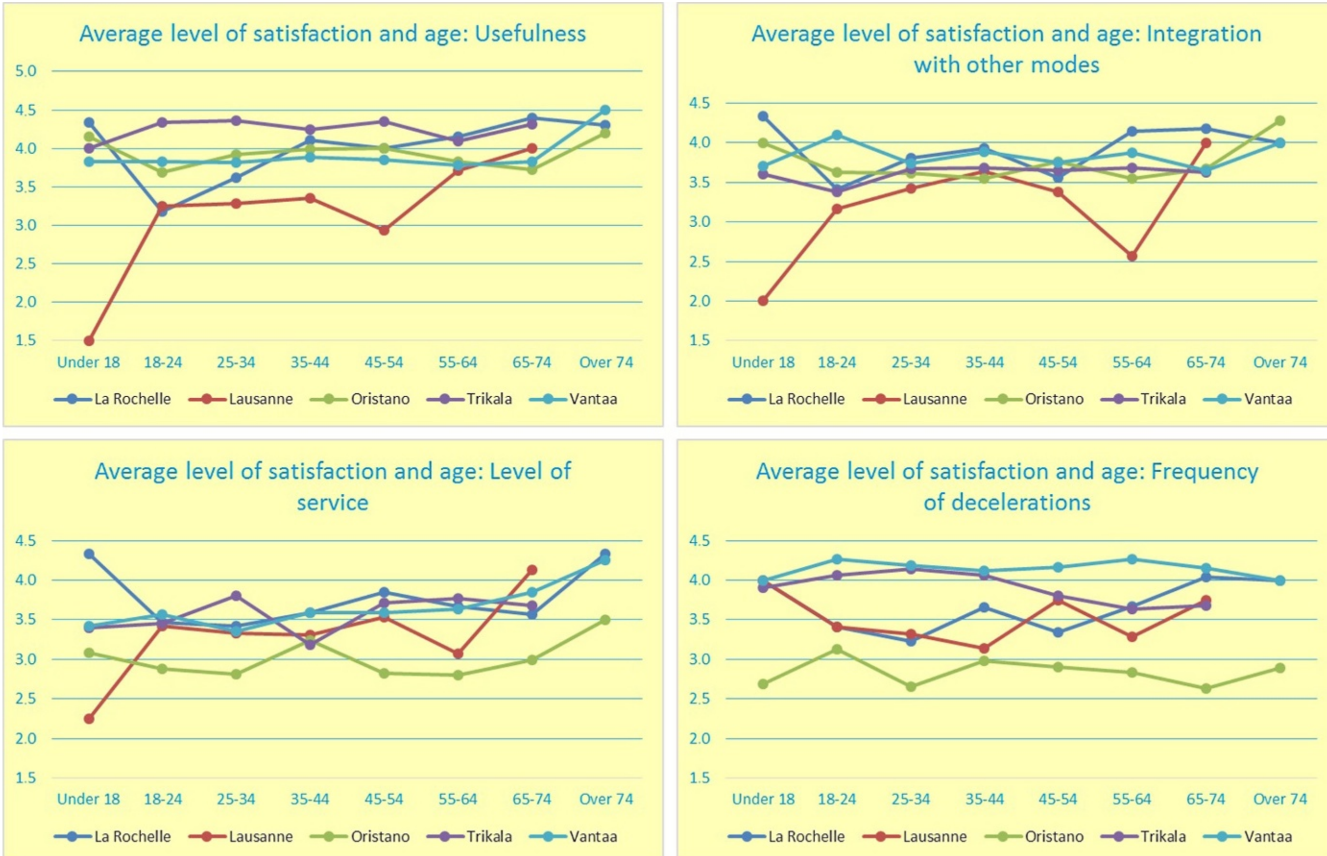

Fig. 4.18 User acceptance indicators and age.

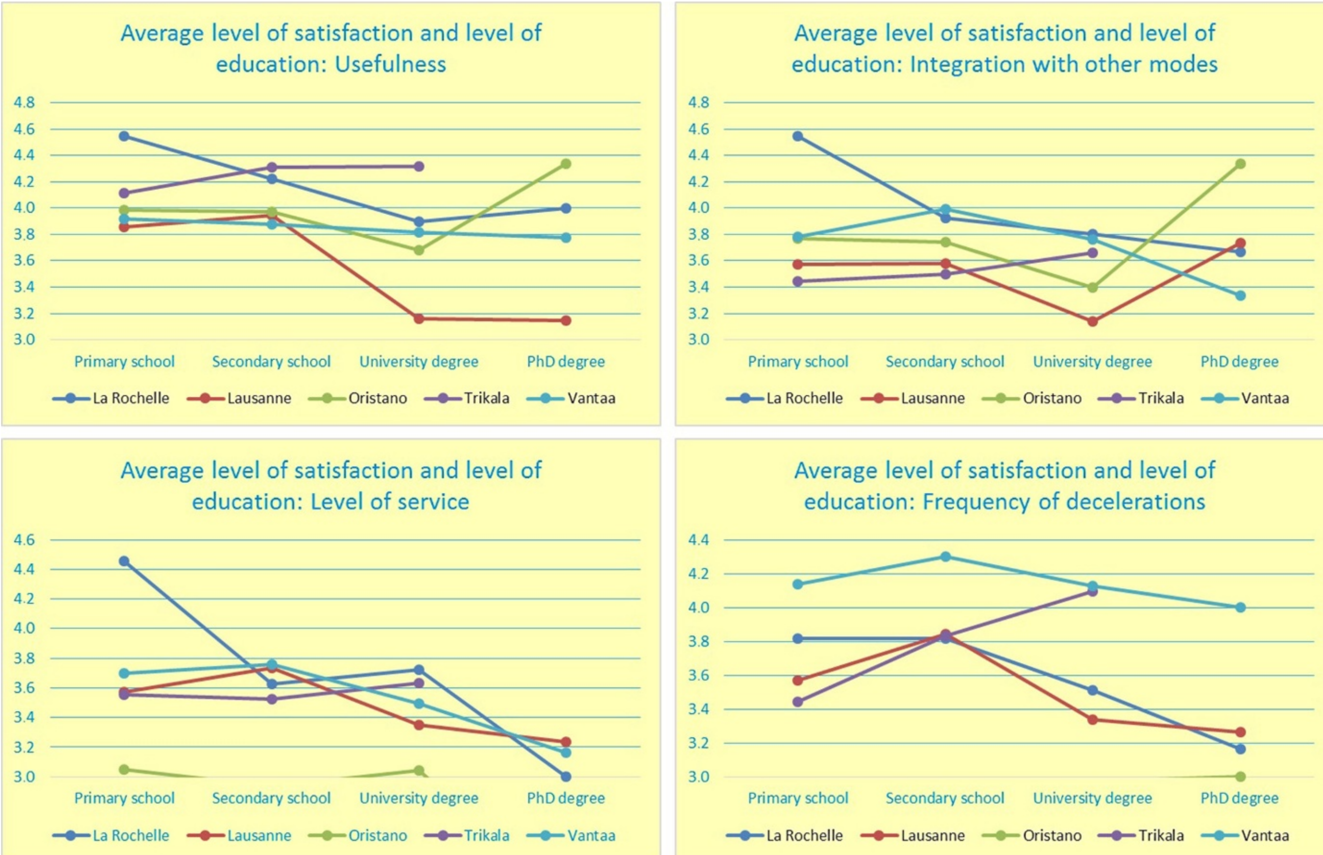

Fig. 4.19 User acceptance indicators and level of education.

Fig. 4.20 User acceptance indicators and employment status.

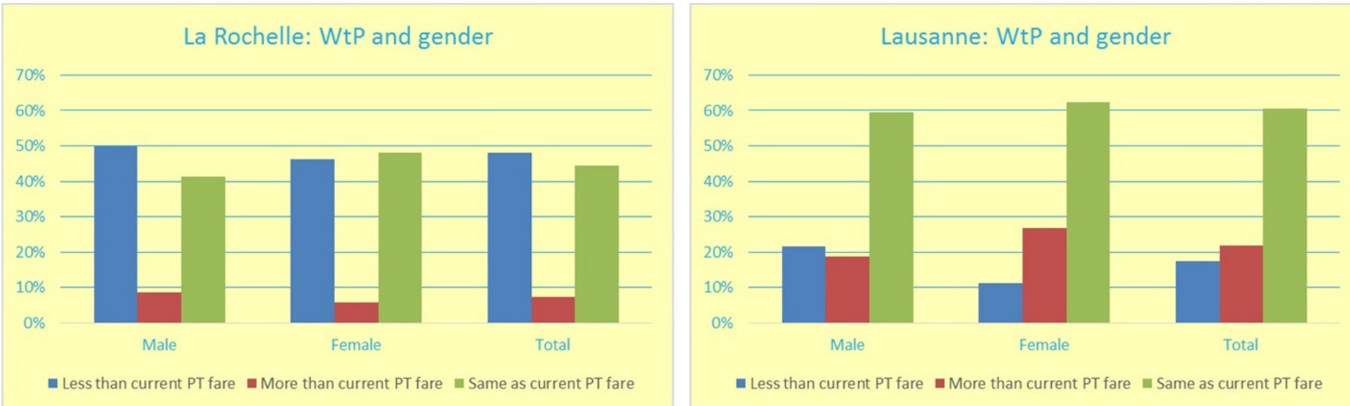

Fig. 4.21 Willingness to pay and gender.

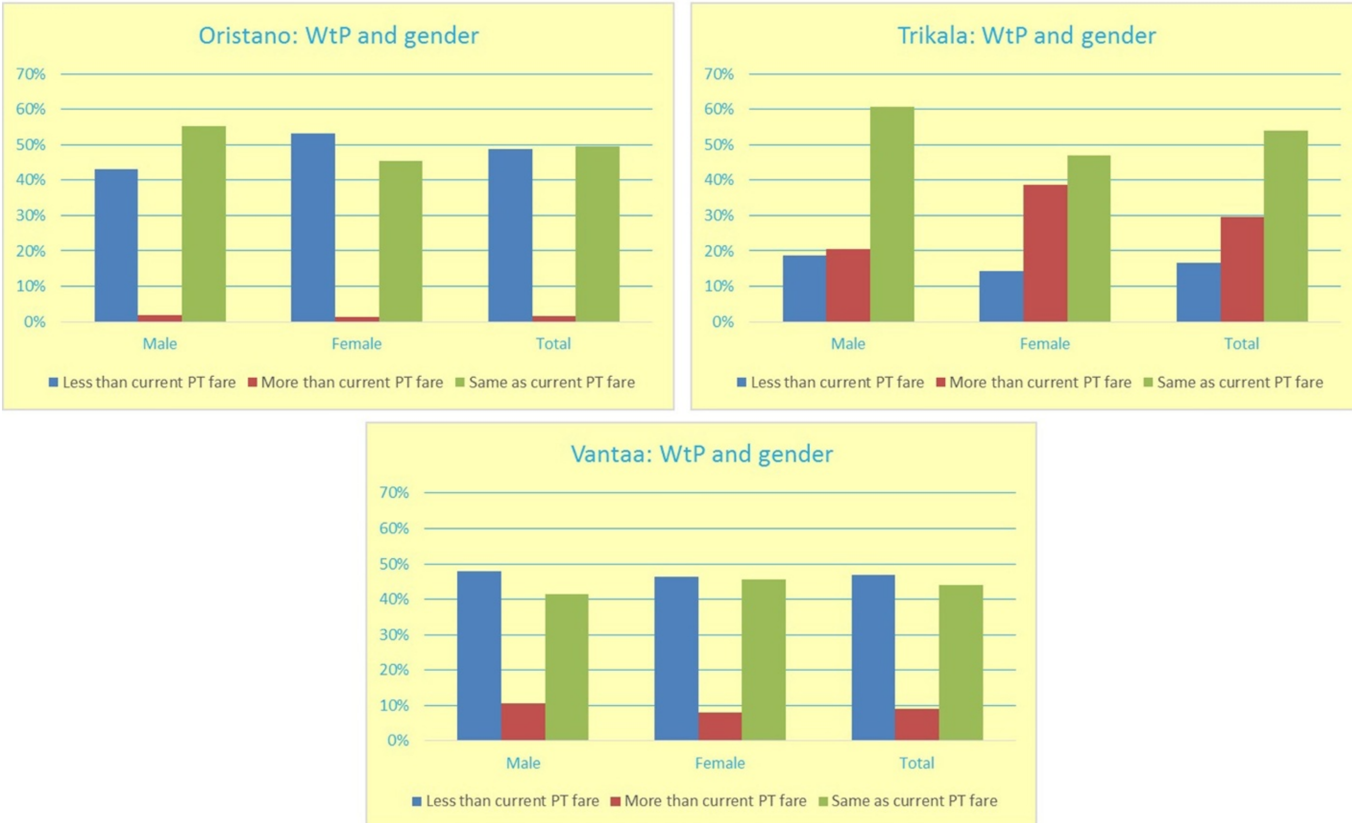

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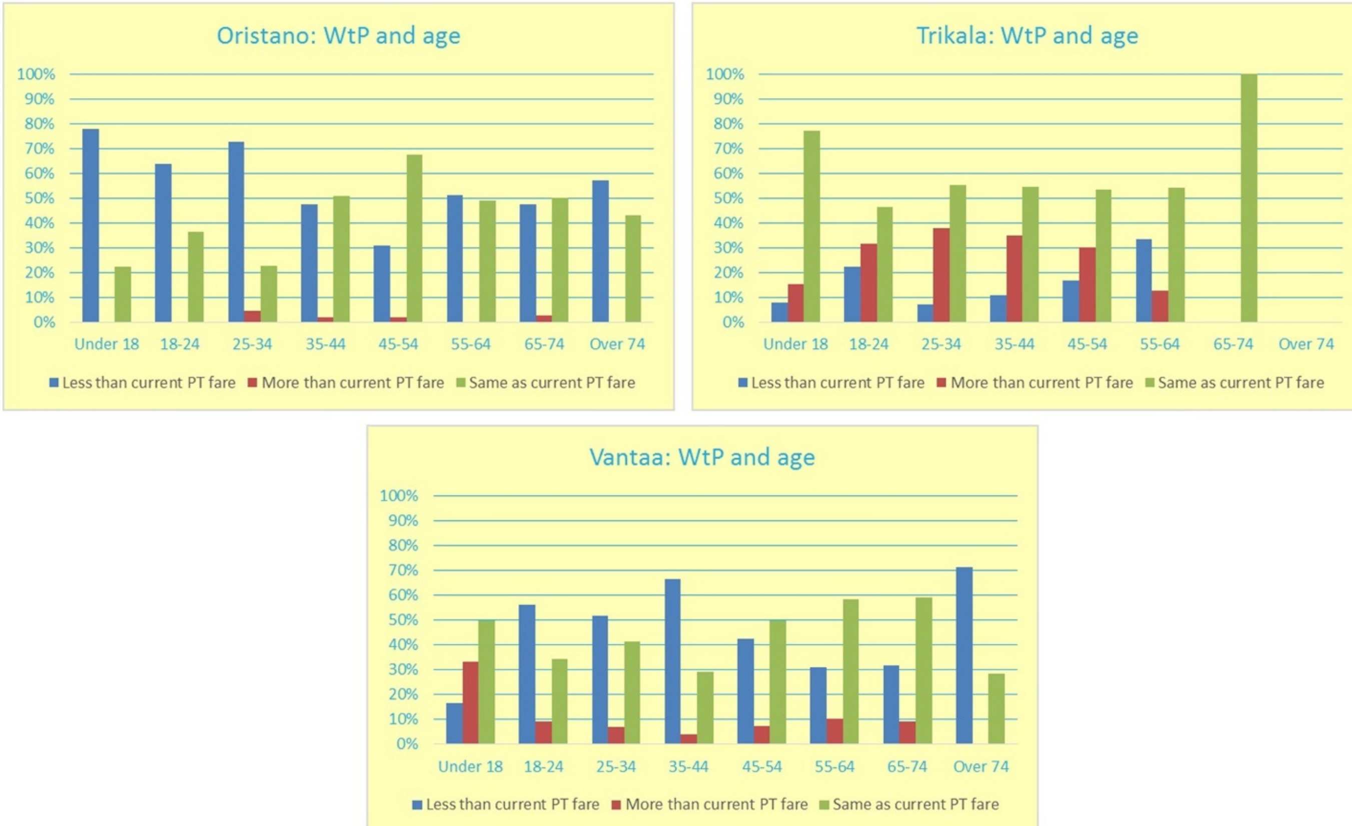
Fig. 4.22 Willingness to pay and age.



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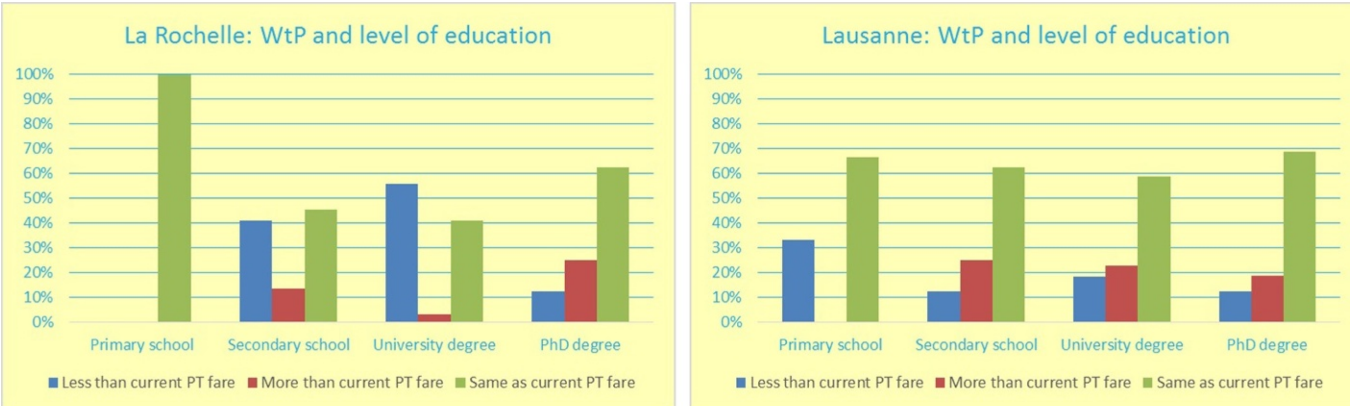
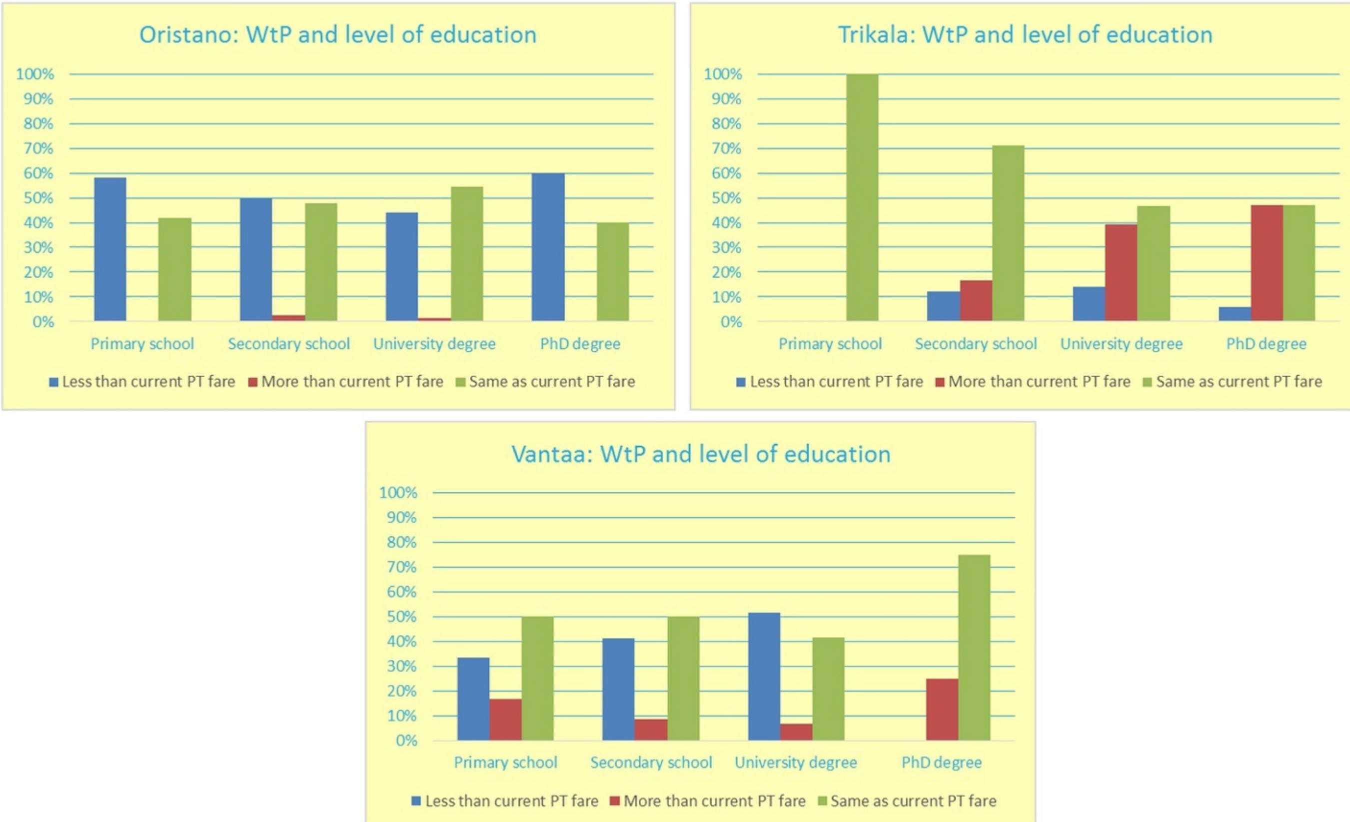


Fig. 4.23 Willingness to pay and level of education.



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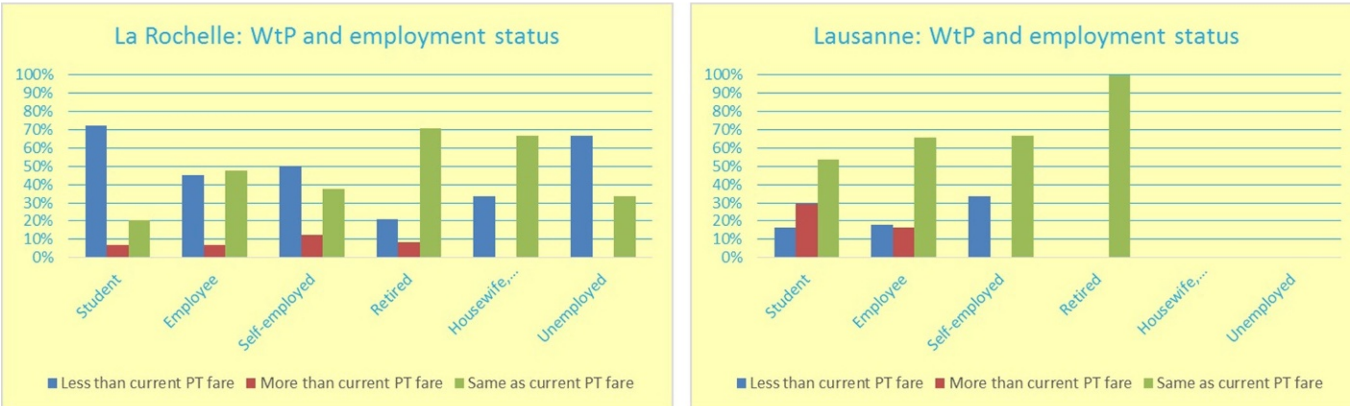

Fig. 4.24 Willingness to pay and employment status.

Fig. 4.24 Cont'd

4.3.6.2 Quality of Service Indicators

The analysis of the effects of socio-economic variables (gender, age, level of education and employment status) on user average level of satisfaction with comfort, jerk and information availability showed no common patterns for all cities except for gender (Figs 4.25–4.28). For all the three quality of service indicators, females always rated, on average, the indicators higher than males in all cities except for Oristano in the case of comfort and information availability (however, the differences between male's and female's rating were small: just one decimal in the case of information availability and five centesimals in the case of comfort).

The perception of safety (Fig. 4.29) showed no common patterns for all cities.

4.3.7 MAIN FINDINGS

The main findings of the comparative evaluation of users' level of satisfaction with the ARTS system in the cities hosting the demonstrations can be summarised as follows:

- Level of satisfaction with user acceptance indicators. The results relating to user acceptance of the ARTS service were in general positive in all cities with average ratings above mean values. Usefulness of the service obtained the highest ratings in all cities except for Lausanne (in which the average values of all indicators were more or less the same). Level of integration with other transport modes obtained good ratings in all cities. Level of service indicators (on-board time, waiting time at stops and frequency of deceleration/number of times the vehicle has stopped in addition to stops and traffic lights) was lower in Oristano compared with the other cities (this might be explained by the fact that the Oristano demonstrations were a sort of pilot demonstration to test the operation of the automated vehicles and fine-tune their function). In Vantaa, the frequency of deceleration obtained a high rating, but this is due to the fact that in that demo, the ARTS vehicles operated as a shuttle between two terminal stations in a segregated route and, therefore, there were virtually no intermediate stops or deceleration.
- Willingness to pay. In all cities, only a small percentage of users were willing to pay more than the current public transport fare. However, most of them were willing to pay at least the same.
- Level of satisfaction with quality of service indicators. The results relating to comfort, jerk (except for Oristano but this as already said

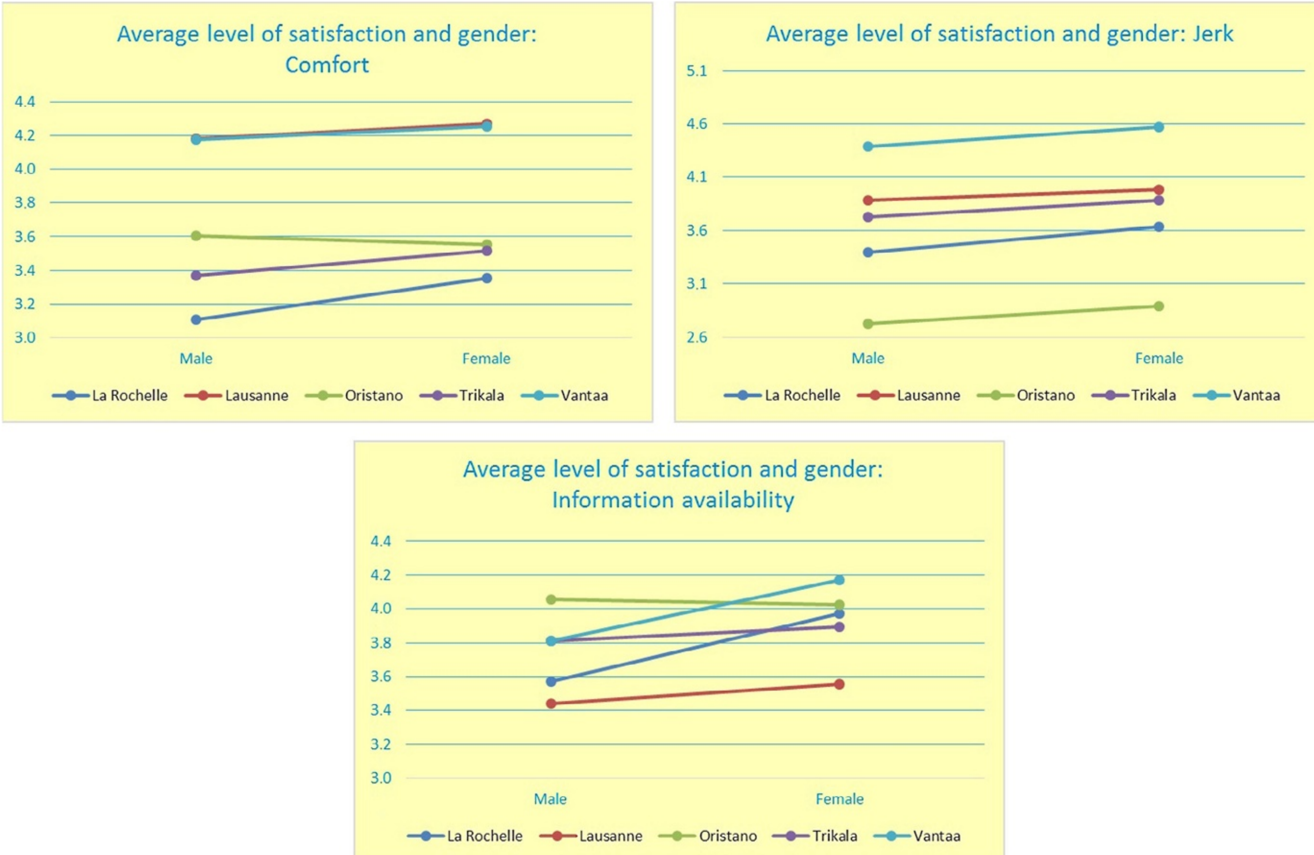

Fig. 4.25 Quality of service indicators and gender.

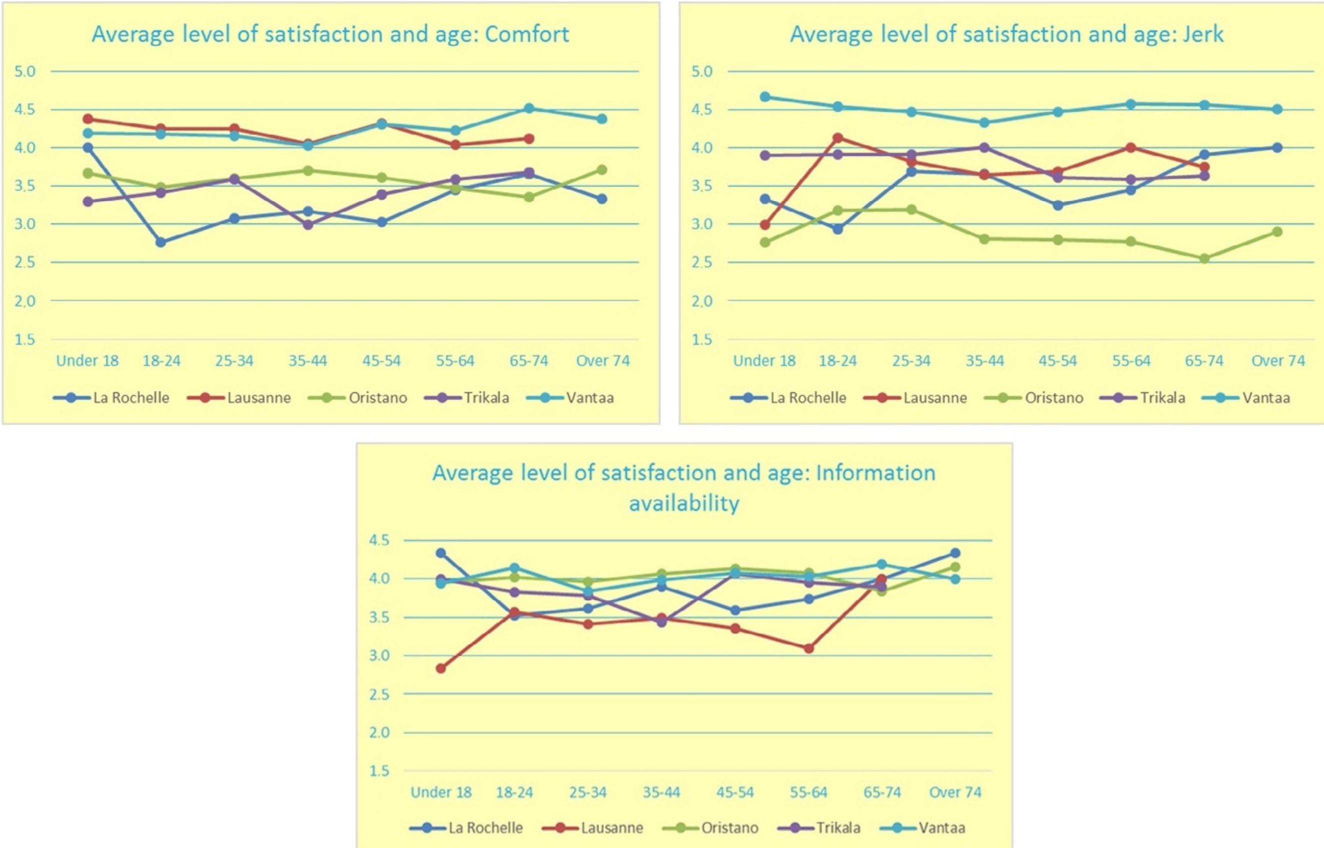

Fig. 4.26 Quality of service indicators and age.

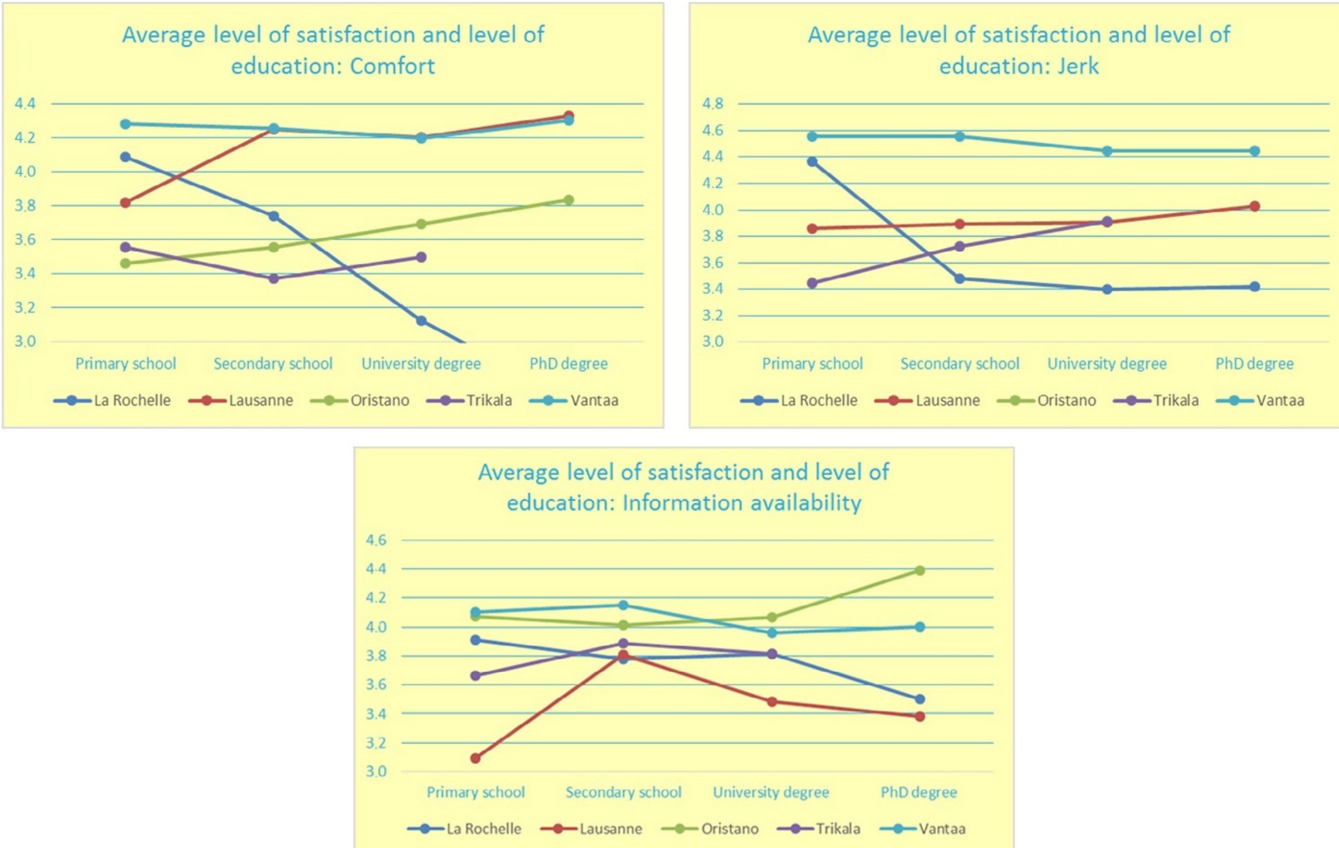

Fig. 4.27 Quality of service indicators and level of education.

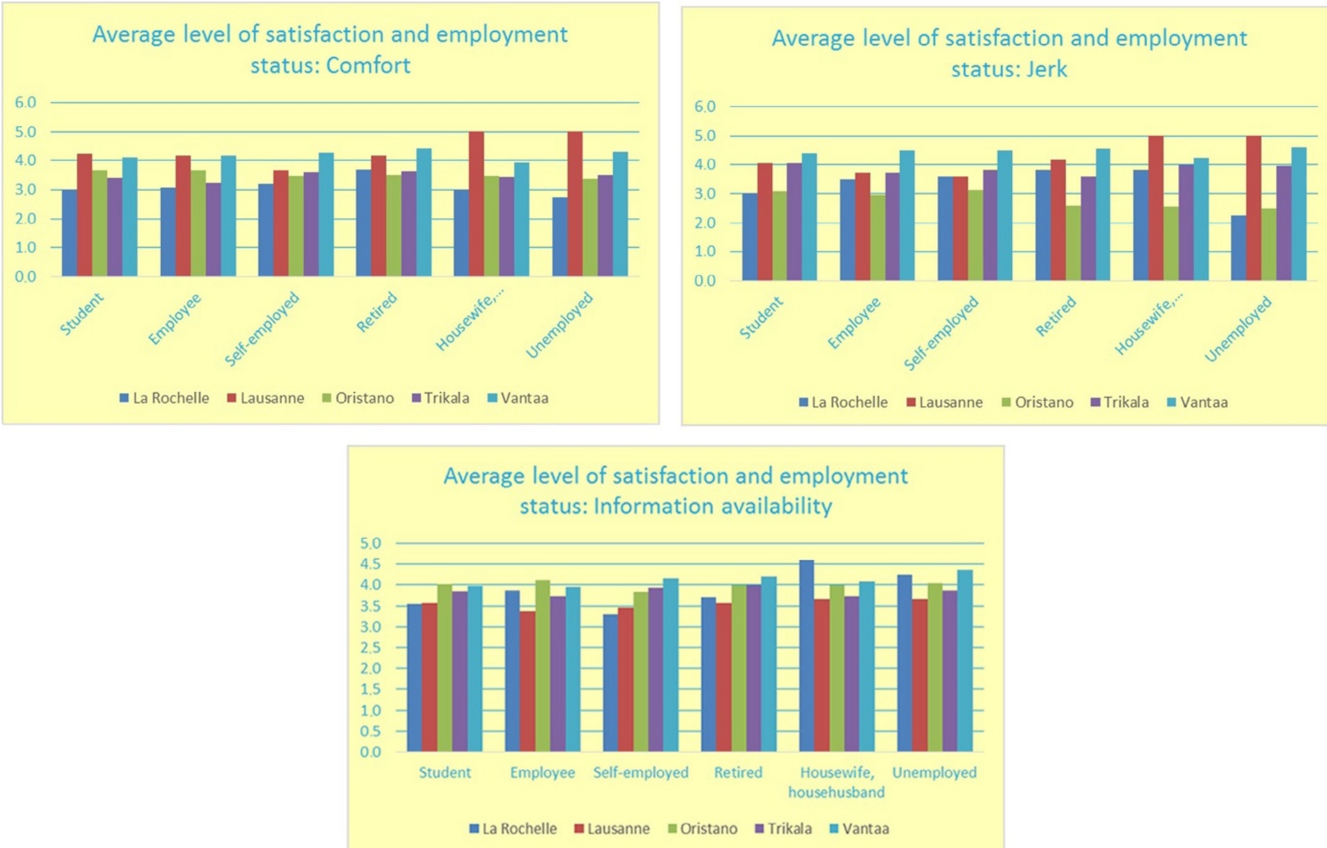

Fig. 4.28 Quality of service indicators and employment status.

Fig. 4.29 Variation of users' perception of safety with socio-economic characteristics.

might be due to the pilot character of that demonstration), information availability and perception of safety (in terms of accident risk) were above the mean value in all cities, but user perception of security (in terms of fear of attack) and user perception of emergency management were rated below the mean value (except for Oristano, where, however, the member of the service operating staff inside the vehicle was easily recognisable).

- Factor mapping analysis. This analysis helps to prioritise the critical factors whose improvement has a major impact in the overall users' perception of satisfaction and enables to provide system designers with recommendations for improvement of system characteristics. The results of this analysis show that in order to increase the overall level of satisfaction of the ARTS service, designers should focus on choosing more appropriate place/route for the ARTS service paying attention to provide adequate integration between the ARTS and the other transport modes. Furthermore, designers should also improve the level of service focusing more on waiting time at stops and on-board time rather than on frequency of decelerations.

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CHAPTER 5

ARTS Certification and Legal Framework

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CHAPTER 5.1

The Certification Approach for ARTS

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†AutoKAB SAS

5.1.1 BACKGROUND

CityMobil2 defined ARTS [1], the procedure to integrate them in city streets [2,3], and compared ARTS safety with conventional vehicles at intersections [4]. This paper presents the procedure to certify ARTS and their road safety. However, the development of such approach has been iterative. First, some rigid rules for urban integration were set; then, this approach to certify their safety was conceived, and then, after application, more relaxed road designs were allowed.

Finally, the certification procedure here described and conceived to be applied to the entire network of ARTS has been divided in use cases, and those use cases were used as the building blocks of the proposed legal approach [5].

This certification approach and the different application examples have been already published in Refs. [6,7] here in this paper; the application of the different steps of the certification procedure to ARTS is presented.

The kernel of the CityMobil2 approach is to mitigate risks directly at the system's design stage by analysing interactions between the ARTS, infrastructure, other road users and surrounding environment [1].

5.1.2 RISK-ASSESSMENT PROCEDURE

The risk-assessment procedure is organised in the following eight steps:

- Step 1: project approach
- Step 2: preliminary hazard risks
- Step 3: FMECA and system design
- Step 4: verification of system safety/functionality
- Step 5: operational description
- Step 6: verification of operational preparation
- Step 7: approval design/operational safety cases
- Step 8: operational testing

Each step corresponds to a verification phase in the workflow.

First, the procedure requires that the involved authorities agree that the proposed procedure is acceptable to issue a certification for the described project (step 1).

Then, the procedure foresees the compilation of a preliminary hazard list and the proposal of mitigation measures, changing the project description until it is agreed that risks are mitigated and the final description is approved (step 2).

The ARTS needs then to be designed according to the specificities of the site and the agreed mitigation measures; changing the vehicle and sensor design could affect the mitigation measures. The system engineering needs to pass failure mode, effects and criticality analysis (FMECA) that will demonstrate that even in case of subsystem failure, the system will still react respecting the prescribed safety targets (step 3).

Step 4 will verify that the functional safety outcome of the FMECA will indeed work.

Step 5 will consider operational requirements for the first time. Weather conditions, hours of operation and lighting conditions will come into play here. Tests will be made to guarantee that the systems reach the same safety level for which they are engineered in all operational conditions.

Step 6 includes operational procedures; the manuals for the operators, their training programme, the maintenance schedule and all the other conditions that might affect in time the effectiveness of the system safety will need to be considered, as well as emergency procedures in case of failure.

Step 7 will define the operational safety cases on the basis of the approved procedures and devise tests on those cases.

Step 8 will be the final tests (dry runs) before the final approval to public opening.

5.1.3 THREATS IDENTIFICATION AND SELECTION OF MITIGATION MEASURES

Step 2 is the kernel of the methodology. As shown in Fig. 5.1, first of all, a list of hazards needs to be compiled and mitigation measures defined to limit or remove such hazards.

Most of the hazards are infrastructure-related. Whether there is a large tree on the sidewalk that obstructs the sensor's view possibly hiding a pedestrian or a kindergarten nearby and kids could possibly come out running in the street, such hazards can normally be mitigated with infrastructure revision. The speed profiles defined in Ref. [2] are in fact done so as to mitigate the hazards only by reducing speed; if on the contrary infrastructural measures are taken, speed might not be reduced. The final project description (final blocs in Fig. 5.1) that goes to approval is the result of such process.

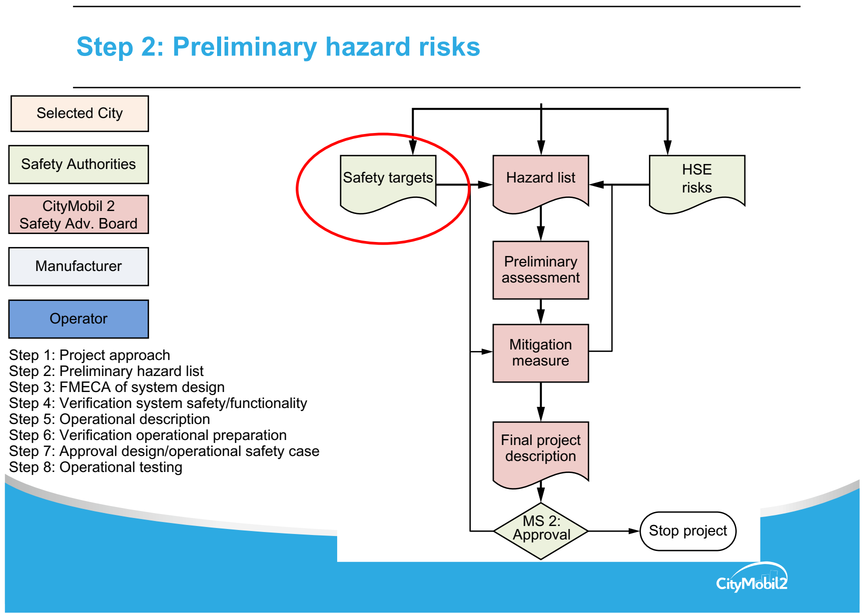

Fig. 5.1 Step 2 of the CityMobil2 certification procedure.

The approaches described in Ref. [3] and verified in Ref. [4] to infrastructure modifications are generic and work on most infrastructures; however, the procedure is conceived to repeat the application of this methodology on each section of the infrastructure.

Five actors are involved in the process: the city authorities who manage the infrastructure; the safety (or certification) authorities, normally the national ministry; a safety board from the project; the ARTS manufacturer; and the ARTS operator. Each one has tasks to accomplish. In Fig. 5.1, each of these actors has a box on the left side, and the tasks of each actor are correspondingly reported in the diagram. For example, it is the role of the safety authority to give the safety targets (circled in Fig. 5.1) at the beginning and provide a list of health and safety (HSE) risks they want to be considered.

The actors in the figure are specifically those of the CityMobil2 project, but using the procedure out of the project list and roles of the actors should be reviewed.

Safety targets are a crucial input to this certification procedure and are health and safety risks to consider. In CityMobil2, the safety target was rail-like, meaning 100 times safer than manually driven cars. How safe is the safety target leads to huge differences in the results. If the target is zero accident, even very improbable events become hazards and need to have

countermeasures; if, on the other hand, the safety target is less stringent, also safety requirements can be less so. To explain a little better, a car kills two pedestrians every billion vehicle kilometre. This is a very low number that nevertheless bring thousands of deaths per year. To improve the safety of pedestrians on streets, safety requirements need to be considered even in very improbable situations.

Step 2 of the methodology defines how to mitigate hazards depending on the risks and the safety targets defined by the certification authority.

5.1.4 FMECA AND SYSTEM VERIFICATION

Steps 3 and 4 of the procedure design the system (including the vehicles) and test them to prove they are safe specifically on the infrastructures defined and approved by step 2.

Fig. 5.2 highlights (in the circle) as critical the failure mode, effects and criticality analysis (FMECA) where the vehicles are tested to be safe and fail being safe in all the specific circumstances they might meet on the site.

The procedure is derived from the EN 50126 technical standard. It is the technical standard normally used to certify automated metros and transport

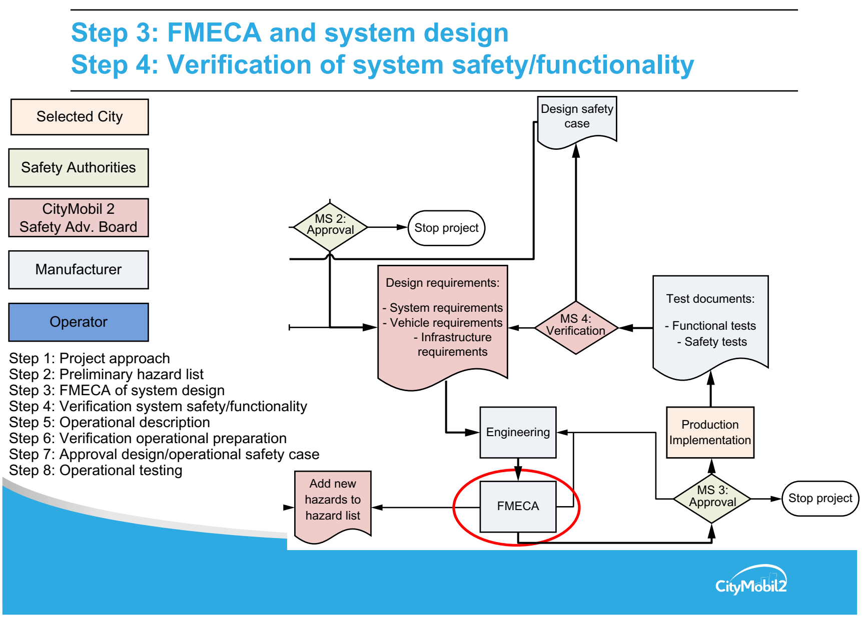

Fig. 5.2 Steps 3 and 4 of the CityMobil2 certification procedure.

systems. For these systems, in which infrastructural investments are higher than those for the rolling stocks, the latter is often adapted to the first.

Investments for ARTS are much smaller, and ARTS vehicles will need to be standardised (sooner or later); in CityMobil2 however, the vehicles could be designed according to the needed specifications, thus making the project free to engineer as needed, and the procedure could be followed.

For the future of ARTS, minimum technical characteristics for the vehicles (not defining the technology but its performances) should be defined, and step 2 of the methodology should define the countermeasures to the hazards depending on the vehicle performances.

5.1.5 VERIFICATION OF OPERATIONS

Steps 5 and 6 bring in the operational dimension. Besides adding the operator to Fig. 5.3 (the darkest boxes are for the operator who so far was not involved), steps 5 and 6 add the complexity of the changing operating conditions. For automated vehicles, weather conditions can have a huge impact on sensing technology and vehicle control, thus requiring to assess the weather and decide when to diminish the performances and when to stop the service.

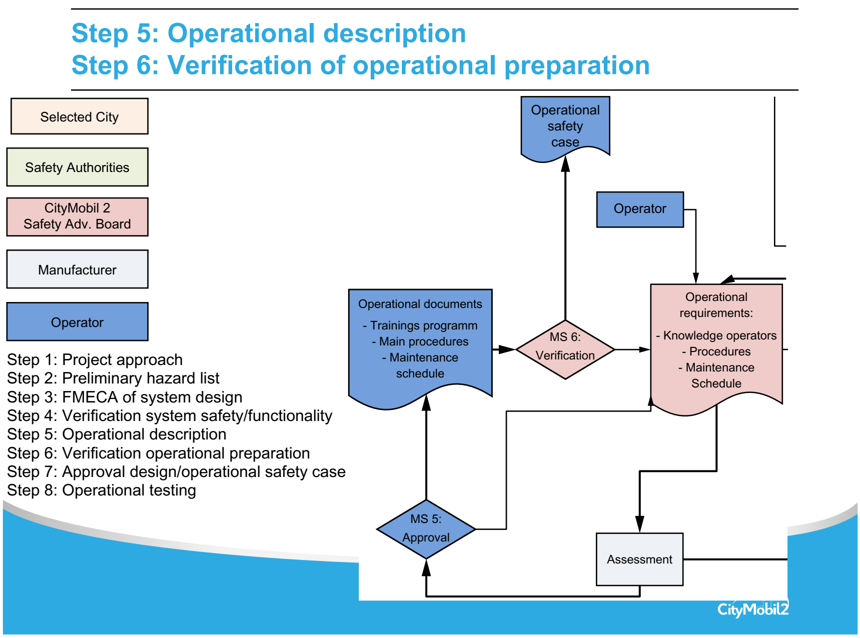

Fig. 5.3 Steps 5 and 6 of the CityMobil2 certification procedure.

More in general, there must be a procedure to verify that the many technological (and less so) systems are all well-performing that any problem can be detected before the vehicle is sent out in service or as soon as it presents itself.

In procedural terms, the operational documents have to be written (and approved) and the safety cases in the different operational conditions constructed and verified.

If the infrastructures are divided in sections with a standard design, the vehicle can become standard and the operational conditions standardised; the same set of infrastructure-vehicle-operation can be replicated in different sites without recertification. This is the concept at the basis of the proposed legal approach [5]; use cases defined as above can be certified and transferred simplifying the procedure and lowering costs. This is doable as long as safety targets are the same for all.

5.1.6 CONCLUSIONS

CityMobil2 is derived from the rail technical standard EN 50126, a certification procedure applicable to an entire transport system in a site to guarantee respect of the safety targets set by a safety authority.

Such procedures comprising eight steps and used within the project to define typical infrastructural adaptations and a technology for ARTS can be used to certify use cases made of infrastructural sections, technology and operational conditions each of which could be easily transferred.

ACKNOWLEDGEMENTS

The certification approach has been developed within CityMobil2's Work Package 26 led by ERTICO. It has been an intense cooperation between system design manufacturers and legal experts. Special acknowledgments need to be given to Andras Csepinszky and Gabriele Giustiniani who worked to this project, respectively, when working for ERTICO and Ingegneria dei Trasporti but who left them before the end of the project and the completion of this book.

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CHAPTER 5.2

Existing Legal Barriers and the Proposed CityMobil2 Approach

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5.2.1 THE LEGAL PROBLEM FOR AUTOMATED VEHICLES

Automated vehicles are not legal on roads, or at least, the matter is unclear [1], and no national ministry takes the responsibility of releasing license plates to automated vehicles.

This matter is regulated by the national road codes and at international level from the Geneva [2] and Vienna [3] conventions. Both conventions define the driver as the person in control of the vehicle, and though they do not explicitly say that the driver is on board (conventions apply to flocks of animals as well, and a person on board would not make sense), when translated in the national laws, the driver is almost always assumed to be present and to be on board.

With the international discussions in mind, many countries, such as the United Kingdom, the Netherlands, Sweden, Finland, Spain and Greece, have taken a pragmatic step to consider that the problem does not lie necessarily in the international texts but rather in their own national regulations, traffic code and type-approval process. Therefrom, a wave of national studies has analysed and proposed national dispositions to allow, first, the testing of the vehicles on specific public roads and, second, to allow future market introduction of such vehicles.

Germany has recently announced that the same principle is true for the testing of the AV on the A9 highway test bed. France is formalising the process through a decree requiring a request to the ministry in charge for transport. At the same time, the US state of California has pushed in a law-making process that may eventually serve as a good practice for many European member states.

However, today, with the exception of Greece that passed a law [4] saying a bus drive can be remoted, there is no legal framework allowing automated driving.

5.2.2 THE CityMobil2 APPROACH

CityMobil2 has defined ARTS and the infrastructures they can use [5], classifying them in segregated and dedicated with the first physically protected against external intrusion and the second certified for safe ARTS use but open to other users.

The legal framework proposal is to divide the road infrastructure in two independent but connected infrastructures. ARTS have dedicated or segregated lanes, which may intersect with lanes for manually driven vehicles (always with traffic lights and road-side sensors that control respect of lights) and access for manually driven vehicles to some of the ARTS lanes, whilst ARTS cannot access 'normal' lanes. Pedestrians and cyclists crossing at given intersections are always possible, whilst on certain lanes, they can even share the way with ARTS.

Each section of ARTS infrastructures has to be certified according to the procedure in Ref. [6]. The infrastructure is divided in sections, and each section, with the technology and the control, is a use case. As long as the safety targets are the same, a certified use case would not need recertification, and all European member states could share the database of certified use case making it easier to certify ARTS everywhere in Europe.

Besides the technical approach, it was necessary to set the common legal framework that has been set by writing a proposal for a European harmonisation directive.

5.2.3 CHARACTERISTICS OF THE PROPOSED HARMONISATION DIRECTIVE

Technological evolution allows the implementation of road systems based on fully automated drive solutions. Nevertheless, there is no harmonised regulations in Europe in order to ensure the setting of these automated road-transport systems. The European Union is in need of a directive ensuring the harmonised regulation of ARTS.

Such a directive has the following purposes:

- Harmonising the type-approval procedures
- Harmonising the authorisation procedures for testing and development of automated road-transport systems
- Setting rules on civil liability

Harmonisation can only be obtained laying down a common legal framework applicable to any categories of automated road-transport systems substituting the former type-approval concept of approving one vehicle per type to a type-approval on use cases; each type of automated vehicle is approved on a number of use cases for which it passed successfully the agreed tests.

The first thing to harmonise between different member states is a system of automation safety targets (ASTs) and automated safety indicators (ASIs) for monitoring the system's performances.

The proposal sets the rules on civil liability establishing a common framework of strict liability for remedying damages caused by automated road-transport systems. The principle of liability has to be structured so that whoever causes the malfunctions pays. Manufacturers and managers will be induced to adopt best practices to minimise the risk of damage.

Finally, ARTS operating within a member state needs to be covered by insurance; each national law should provide for the insurance of the whole system against civil liability.

5.2.4 HOW TO MAKE OF THIS PROPOSED APPROACH THE CERTIFICATION PROCEDURE FOR AUTONOMOUS VEHICLES TOO

As shown in Ref. [5], autonomous vehicles and ARTS can have a first convergence point on level 4, the first moment in which SAE defines that there is no need of a driver on board. Level 3 driving functions can be considered as level 4 functions, limited in time and giving back control to the driver at the end. Level 5 can be obtained as a collection of level 4 use cases on 100% of infrastructures.

The infrastructure is divided in use cases that are defined by the following:

- The geometry of the road
- The other users allowed
- The external conditions influencing sensor field of view and performance
- The interaction with other road users and the infrastructure
  - DSRC
  - Road-side sensors
  - Digital mapping

Any different combination of parameters is certifiable; it is just a different use case.

This way, the legal approach conceived for ARTS by the CityMobil2 project can be applied to any automated vehicles.

5.2.5 ONE EXAMPLE OF APPLICATION TO AUTONOMOUS VEHICLES

The example reported here is what would happen to certify a stretch of urban motorway for autonomous vehicles following the CityMobil2 approach, setting the safety target twice as safe as manual driving.

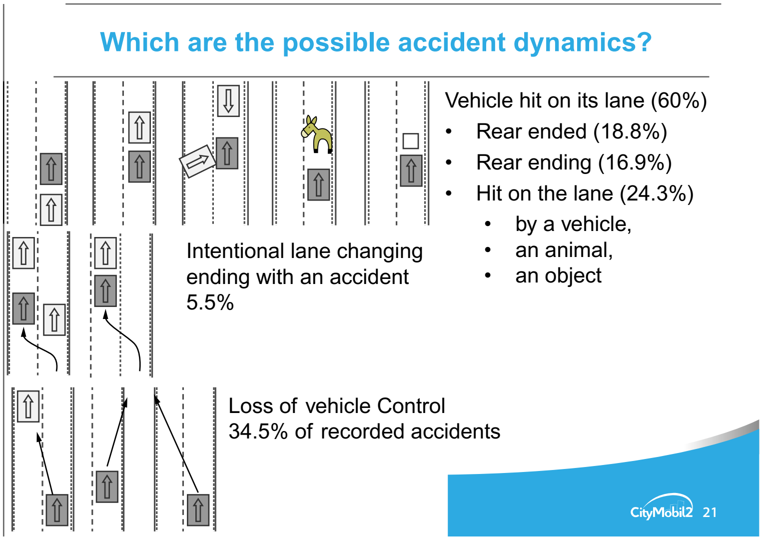

Fig. 5.4 Accident-igniting manoeuvres and their percentages according to SafetyNet in-depth analysis.

Fig. 5.4 depicts all possible accident dynamics on a stretch of multilane urban motorway. The percentages in Fig. 5.4 are percentages of the manoeuvre igniting the accident casual chain. The figures are taken from the European project SafetyNet that analysed in depth a thousand of accidents reconstructing the accident dynamic and creating a European database out of it. Naturally, a thousand accidents are a far too small sample to have a statistical significance but are accurate enough to give an example.

How the automated vehicle can be twice as safe as manual:

- Demonstrating that the technology is absolutely safe in lane changing
  - 5.5% of accident-igniting manoeuvres saved
- Demonstrating that the technology never loses control of the vehicle (not even if an animal jumps in front of it)
  - 34.5% of accident-igniting manoeuvres saved
- Demonstrating that the technology cuts in half rear-ending (reducing them to zero would mean brick-wall stop distance that is almost impossible to keep on motorways)
  - 8.5% of accident-igniting manoeuvres saved
- Demonstrating that the technology reduces of a third rear-ended (increasing distance from the vehicle in front and decreasing speed each time it is closely followed)
  - 6.2% of accident-igniting manoeuvres saved

- Demonstrating that this behaviour will only increase 20% of the accidents in which the automated vehicle hits the object in the lane to prevent losing control of the vehicle
  - 4.8% of accident-igniting manoeuvres increased

  Overall, the accidents are decreased by slightly more than 50%.

To demonstrate that the technology is capable (in any operational conditions) of respecting such performances, each manoeuvre will have specific test devised. Most manoeuvres to test will be common to different use cases reducing the testing burden, and some will be specific of the use case.

Then, an FMECA will need to prove that the vehicle is capable of detecting critical malfunctioning of the system that would prevent safely driving the use case and either slow (if this is enough to restore test-passing performances) or stop the vehicle (level 4) or give back the control to the driver (level 3).

Tests will be weather-dependent:

- Working conditions in terms of visibility and rain intensity will need to be stated, and the test should be passed in those conditions.
- Automated driving will be impeded if the weather conditions are worse than those of the tests.

Type-approval procedures today set general standards for the vehicles to respect (e.g. windshield and windshield wipers are certified as are safety belts). However, with this approach, no a priori standard should be used; they should be use-case-dependent.

Crash tests (and seatbelts) will be needed if safety is twice or three times or ten times the current road safety but not needed if the use case is obtained with rail-level safety standards (100 times better than road).

There is a final question on this example, that is, how to get 100 times safer, meaning reducing 99% of the accident-igniting manoeuvres. There is only one way: changing infrastructures

5.2.6 CONCLUSIONS

Automated vehicles cannot circulate on roads today, and a legal framework to allow it and do so in a harmonised way is necessary. CityMobil2 proposed one approach that legally could be implemented in Europe with a harmonisation directive. Based on the CityMobil2 certification procedure, the technical part sets aside part of the infrastructures to be 'dedicated' (not exclusively) to ARTS. The directive sets liability and insurance need. This procedure can be adopted for any automated vehicle, and an application

example on a motorway, which does not require any infrastructure modification setting the target for the automated vehicles to be twice as safe as a manually driven one, is provided.

Though it is not its objective, the paper proves how automated vehicle certification for safety cannot be done ignoring the infrastructures, and in fact, the main benefit of full automation will be taken only when the infrastructures are reconceived to allow automated vehicles to be safe.

ACKNOWLEDGEMENTS

This paper is the result of the work of Work Package 26 of CityMobil2 led by ERTICO. On this specific topic, the legal work was led by Professor Enzo Cannizzaro and his team at the University La Sapienza in Rome. The proposal for a harmonisation directive was written by them.

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CHAPTER 5.3

The Greek New Legal Framework

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5.3.1 INTRODUCTION

Significant steps have been undertaken to promote the use of autonomous vehicles probably pushed by advances in non-European countries and predominantly in the United States. Still in several cases, fully or partially autonomous transport systems are constrained by existing legislation. Regardless of the strong will on behalf of policy makers to remove these barriers, it will take time for the existing regulatory system to adapt to the introduction of such systems. It is expected that this will be an incremental process that synchronises with (and possibly follows) incremental technical advances. In this aspect, it should be noted that previous EU projects have acted as a catalyst for paving the way for legislative acts that will overcome existing barriers, from different operational perspectives. It is highly accepted that a continental (if not global) approach is needed. Automated vehicles should be able to undergo a similar certification process and should be (finally) homologated with the same criteria worldwide. However, for the time being, this approach is not only unfeasible but also very time-consuming.

Since technology usually paves the path, individual projects—like CityMobil2—pushed forward for practical legislative acts that could facilitate in a case-by-case scenario the actual operation of automated vehicles in a national (or local) level. These attempts cannot be considered as a global solution to the existing legislative gap but can certainly be regarded as a first (practical) step forward.

5.3.1.1 Regulatory and Legal Framework for Automated Vehicles

Road traffic is a highly regulated area as it bears huge risks for all traffic users in public spaces. The automation of vehicles changes the driving risks in many regards and therefore requires new rules and regulations. Thanks to the push by Google and, recently, by the car manufacturers, these changes are now taking place.

The Vienna Convention on Road Traffic of 1968 [1] is an international treaty designed to facilitate international road traffic and to increase road safety by establishing standard traffic rules amongst the contracting parties.

The road regulations in the various countries must be in accordance with the convention, if the treaty has been ratified (it has not in the United Kingdom and in the United States, but they have ratified the previous convention (Geneva 1949)). One of the fundamental principles of the Vienna Convention is the concept, as laid down in Article 8, that a driver is always fully in control and responsible for the behaviour of a vehicle in traffic.

Article 8 (1): Every moving vehicle or combination of vehicles shall have a driver...
(5): Every driver shall at all times be able to control his vehicle...

The Inland Transport Committee (ITC) of the United Nations Economic Commission for Europe (UNECE) [2] is a platform for international cooperation to facilitate the international movement of persons and goods by inland transport modes. The ITC has two permanent subsidiary bodies whose work is relevant for the introduction of automated driving: (i) The Working Party on Road Traffic Safety (WP.1) is a permanent intergovernmental body responsible for administering the international road-traffic-related conventions including the 1968 Convention on Road Traffic and the 1968 Convention on Road Signs and Signals, and (ii) the World Forum for Harmonization of Vehicle Regulations (WP.29) is a permanent intergovernmental body, responsible for the harmonisation of technical vehicle requirements.

In March 2014, WP.1 approved an amendment to the Vienna Convention of 1968 saying that 'systems which influence the way vehicles are driven', and other systems that can be overridden or switched off by the driver are deemed to be in accordance with Article 8. This amendment has been formally approved and came into force in March 2016 but still demands that every vehicle must have a driver.

A further amendment process is therefore necessary to permit driverless vehicles on public roads. Systems with high or full automation are mostly still incompatible with the Vienna Convention, even with the 2014 amendment, because a driver may not be required in these systems, depending on the use case.

Within the EU, mass-produced cars may only be used on public roads if they are type-approved in compliance with the administrative procedures and technical requirements established by the Framework Directive 2007/46/EC [3]. In 2014, experts started evaluating the technical requirements that innovations enabling automated driving shall comply with to ensure safety. This work was completed within 2016 with a view to its potential adoption by the World Forum for Harmonization of Vehicle Regulations in 2017. A particular focus is on self-steering that is allowed at the moment but only up to 10 km/h (mostly for automated parking).

5.3.1.2 From Automated Vehicles to Driverless Vehicles

Although driverless road vehicles have been demonstrated since the 1990s and are much talked about, it can be seen from the previous discussion that we are still a long way from allowing them on public roads. The car manufacturers, who are very active on driving automation, are not particularly in favour of full driving automation (SAE levels 4 and 5) since this might change their business models with the arrival of automated taxis.

However, automated road vehicles are already in exploitation, but not on public roads. They already exist in specific environments such as agriculture, mining, harbours or factories. And three cases of 'people movers' using automated road vehicles (and not mechanically guided vehicles such as automated metros) have been in operation since the late 1990s, whilst others have been tested for shorter periods of time in several environments. In the case of people movers, the systems in place had to be certified using existing regulations concerning public transit. This meant that they had to be certified according to the regulation of automated trains, a complex and lengthy procedure. They also had to operate on a dedicated infrastructure, therefore removing them from the traffic regulations.

For a brief overview of the current legal situation, one can address also this [4].

5.3.1.3 The CityMobil2 Challenge in Trikala

Within CityMobil2, the challenge was somehow different. The requirement was to put a driverless automated vehicle (a fleet of) on public roads with no segregation from actual traffic and no explicitly dedicated infrastructure (e.g. hardly dedicated lane) in a city centre with no restrictions on time of operation. Thus, the local consortium had to find a way to overcome legal barriers whilst providing all safety measures to ensure a proper operation and win people's trust at the same time. The time window for the Trikala demonstration was set for the second half of 2015, and the local consortium had approximately 1 year and a half to prepare.

5.3.2 EUROPEAN SITUATION

Whilst in the United States different states have progressed in allowing autonomous vehicles on their roads [5], the situation in Europe is rather fragmented [6]. As CityMobil2 is a European project, the starting point was to assess the European legal situation in detail. Evolutions in the other side

of the Atlantic were difficult to follow as (at least at that time) no federal approach was followed, whilst individual state-based approaches have been implemented.

In Europe (and mainly through the effort of several European projects such as CyberMove, CityMobil and CityMobil2), steps have been taken to evaluate the possibility to operate such fully automated vehicles (or autonomous to say they operate without a human in the loop) on public roads. It should be noted that the vision of autonomous vehicles used for public transport is not exactly new [7]. Although most demonstrations that took place in these projects had a 'steward' on board, ready to take over the driving (or at least the emergency stopping), some countries put in place national rules to allow driverless operation, whilst other countries have decided it is not against their national regulations for such vehicles to operate. In general, several EU member states have progressed (or are expected to do so in the coming 1–2 years) to legally allow driverless vehicles on their public roads:

- In Germany, a joint work of the working group of the German Federal Highway Research Institute (BASt) produced a study for an extensive legal assessment with respect to regulatory law and liability law and offered a classification of the degrees of automation from a policy perspective. This definition was at the source of the NHTSA levels and eventually the SAE standard. The German Federal Ministry of Transport and Digital Infrastructure established a Round Table 'Automated Driving' in November 2013.
- In the Netherlands, as of July 2015, the Ministry of Infrastructure and the Environment has opened the public roads to large-scale tests with self-driving passenger cars and lorries. The Dutch rules and regulations have been amended to allow large-scale road tests.
- In the United Kingdom, as part of the 2013 National Infrastructure Protection Plan, the government pledged a review of the legislative and regulatory framework to enable the trialling of driverless cars on UK roads. The UK government published a detailed review of regulations on 11 February 2015, examining the regulatory framework for the safe testing of driverless or fully automated cars [8]. A code of practice will be published in spring 2017 for those wishing to test driverless vehicles on UK roads.
- In France on 17 August 2015, the bill on the energy transition was adopted. The energy transition law provides in Article 37, IX that the French Government is authorised to adopt 'by ordonnance' any legal

measures to allow the operation of passenger or freight vehicles that are partially or totally automated, for experimental purposes and under safe conditions for all road users by providing, if necessary, an appropriate liability regime.

- In Finland, the Ministry of Transport and Communications has been preparing an amendment to the Road Traffic Act that would allow for driverless robotic cars to drive within a restricted area on public roads. The amendment in question would constitute experimental legislation that would be in force for 5 years starting at the beginning of 2015.
- In Italy, a demonstration of automated vehicles in the city of Oristano, Sardegna, has already took place under CityMobil2. The country was working on the certification process of such vehicles following examples of trams and trains. However, this is currently under discussion for possible modifications. For the time being, autonomous vehicles can be granted testing plates under the supervision of a university and only if a 'steward' is on board.

CityMobil2 has proposed a directive to the European Commission to certify such systems based on a use-case approach. Each time a particular use case has been certified through rigorous testing (meaning the vehicle and also its infrastructure), it can be reused in another place. It now remains to be seen how this approach can be put in place in reality in the various European countries, taking into account the different road regulations. More details on this approach can be found in another chapter of this book. However, in Trikala, a different approach was followed as the timings could not match.

5.3.3 THE GREEK LEGAL PATHWAY

The Greek Ministry of Infrastructure, Transport and Networks in cooperation with stakeholders in the country (e.g. ICCS and e-Trikala) has begun discussion regarding the possibility of allowing driverless vehicles within the Greek transport network from mid-2013. At that point, the city of Trikala was forming its candidature for hosting a small-scale demonstration under the auspices of CityMobil2. The first attempt through networking with CityMobil2 cities' partners was to seek for a homogenised approach with other European countries, with emphasis on those that would host CityMobil2 demonstrations. Although such networking took place, it became evident that a common approach between (at least some) countries was not possible under the time constraints of CityMobil2. Overall, legal

processes are lengthy, and if these involve cross-country issues, then the whole attempt gets very time-consuming. However, it should be noted that a workshop took place in Athens to foster discussions amongst related ministries on 5 May 2014. In that workshop, representatives from the following EU member states took part: Greece, Finland, Germany, Spain, Sweden, Poland, Italy, the United Kingdom, Cyprus, France and Malta. Within the workshop, the following were the main outcomes:

- CityMobil2 presented a proposal for the certification of automated driverless vehicle (across the lines presented in another chapter of this book).
- The issue of legislation for fostering autonomous vehicles on the roads is urgent.
- There was still a long way ahead for reaching consensus as countries not only are in the same timeline but also in some cases follow a different agenda influenced by national (industrial- or policy-related) needs and requirements.

Following the workshop, discussions on a national level have actually pushed forward. The option of basing the certification process on the rail technical certification process was abandoned. The basic reasoning is that it is envisioned that the link between automated vehicles and (automated) trains shall break eventually. The idea of basing the (new) certification process on a process that assumes fixed tracks was considered restrictive for the future full implementation of autonomous vehicles. Although it was widely accepted that the process could be straightforward and probably could have a solid legal basis that could yield quicker results, the fact that future expansions to cope with real-world operation of autonomous vehicles should follow this specific legal path was considered less effective.

Looking for an alternative solution, the issue of the Vienna Convention became a real bottleneck. To overcome this legal barrier, the local partners (ICCS and e-Trikala) proposed to keep the driver on the loop but just change its position and move him/her outside the vehicle. The Vienna Convention mentions that every moving vehicle shall have a driver and that every driver shall at all times be able to control his/her vehicle. It does not explicitly mention that the driver should be ON the vehicle in order for the vehicle to be 'controlled' or to 'have' a driver. Going even further and assuming that a driver can be removed from the vehicle, then, there is no explicit need for having an equivalence of one driver per vehicle. Of course, at the time, the Vienna Convention agreed that it is certain that the countries assessing this did not have in mind such an interpretation and neither

had the intention to facilitate autonomous driving. However, as time and technology move ahead, one can interpret the convention in order to minimise legal implications.

Having agreed that the main concept is keeping the driver but removing him/her out of the vehicle, then, it was just a race against time to make sure that appropriate legislation acts were put in place across this axis to (i) allow the CityMobil2 demonstration (and similar ones in the future) to take place on one hand and (ii) to discourage any possible misinterpretations that the use of autonomous vehicles on Greek roads could be nonregulated on the other.

As a first step towards this direction, the Greek Ministry of Transport, Infrastructure and Networks prepared a legislative act that has been approved by the Greek parliament on 11 December 2014 [9]. In this specific act on Article 48, there is a provision for the operation of autonomous vehicles without a driver on board. In more details, the specific article (§4–8) dictates the following:

- For the time being, the operation of automated vehicles with no driver on board is allowed strictly for research-pilot purposes.
- Such an operation is allowed only if the respective municipality authority and local police and traffic regulation department give clearance.
- Such an operation should have both a time limitation and a well-defined area of operation that will be the outcome of a respective traffic city study.
- Such an operation can be allowed on urban areas and not for use in highways.
- The vehicles shall bear steering and braking systems that are equivalent with a conventional vehicle in terms of operation.
- Such an operation should be monitored in real-time at all times by cameras that can be either mounted on board or put in place in the area of operation (or both).
- There should be available remote control centre that is able to execute emergency stopping of the vehicle(s).
- The operator at the remote control centre should possess a driving license equivalent to the type of vehicle he/she has to operate remotely and will bear the legal responsibility in case of an accident according to existing legislation for drivers.
- Further regulations and specifications will be detailed in a case-by-case scenario by a ministerial decision.

The aforementioned forms a specific framework for the operation of autonomous vehicles that pose significant but distinct requirements. The most

important aspects are that this can be only performed on an urban level with the support of the local stakeholders and that the liability is transferred to the operator at the remote control centre who should be able to monitor and control (emergency break) the vehicle as if he/she was on board.

From the moment the legislative act came into force, discussions amongst all interested parties begun to lay down the conditions that could allow the specific implementation of autonomous vehicles in the city of Trikala. The discussion panel expanded to involve the municipality, the regional authority, the local police and traffic regulation department and in later stages other local stakeholders (such as chambers of commerce). The ministerial decision that was the outcome of these discussions was issued on 13 June 2015 [10].

The specific ministerial decision laid down specific conditions for both the vehicles and the process to be followed. Amongst these steps, the following should be noted:

- Operation is only allowed in a bus lane that shall be (during the operation) dedicated to the autonomous vehicle (excluding other vehicles but not bicyclists or crossing by pedestrians).
- The lane of use should be appropriately marked, whilst signs indicating the operation of the autonomous vehicles (including operational timetable) should be put in place.
- Labelling indicating the absence of a driver on board should be visible both in and outside of the vehicle.
- The vehicle shall respect traffic regulations related to traffic lights, pedestrian crossings and other traffic signs.
- Approval of the operation is upon the local municipality based on a traffic study that will need also to be approved in prior by the local road-traffic police department.
- The maximum operating speed is set at 25 km/h.
- The remote operator shall receive proper and proven training with regard to the vehicle, its operation and its handling.
- The remote operator shall have the (proven) ability to stop the vehicle in case of emergency, in case of loss of visual communication with the vehicle or in case that the maximum number of passengers allowed is exceeded.
- The autonomous vehicle shall have the same (proven) ability to self-steer, break or stop with a conventional vehicle.
- Specific conditions are set for the vehicle layout, chassis, doors, seats and in-vehicle information systems to ensure and safeguard proper driving behaviour.

- Logs of video surveillance of the vehicle's operation should be stored for incident investigation for a period of time.

In order to define the process for granting the permission for operation, we have to define two distinct subperiods:

- The testing period where the presence of an operator on board able to perform emergency breaking is mandatory
- The operation period where under specific conditions the operator could be transferred to a remote control centre

During the operation, a public research or educational institute shall guarantee the proper and safe operation of the autonomous vehicle based on a set of test scenarios that need to be executed during the testing period in order to grant approval for the operation period. During this testing period, operational log files are analysed, and a report being submitted for the analysis of this data is submitted to both the municipality and the ministry.

In order for the testing period to start, the interested stakeholders should submit (i) a copy of any vehicle license issued in another EC country, (ii) any official documentation from one EC country that proves that the vehicle has undergone basic technical testing, (iii) a technical study by an engineer that will be equivalent to those submitted for any new vehicle and (iv) a technical study by a public research or educational institute that will detail the technology elements implemented on the vehicle to ensure compliance with the aforementioned prerequisites. Upon receipt, the local public-transport administration authority shall conduct an on-site technical inspection of the vehicle with a procedure similar to the one followed for conventional vehicles with the presence of authorised public controllers.

Having successfully passed the technical inspection, the municipality is required to submit to the respective department of the Ministry of Infrastructure, Transport and Networks (i) the technical inspection approval, (ii) the approval of the municipality city council, (iii) the traffic study, (iv) the cooperation agreement with a public research or educational institute that will agree to supervise the entire operation, (v) the decision of the city council with regard to the time and area of operation, (vi) the driving license of the foreseen (remote) operators and (vii) the training certificate for the operators. Then, the vehicle is granted with license plates that are in effect for the period of operation.

In order to make the shift from the testing period to the operation period (and consequently move the operator from being on board to the remote control centre), a new set of documentation needs to be prepared. The basic element that will be the decisive factor is the results of the vehicle's

performance to the test scenarios defined and executed during the test period. Upon these results, the involved public research or educational institute shall prepare a technical study detailing the results of the tests and proposing approval or not of the operation period. The municipality shall consult the specific study and shall adopt its results or not and shall respectively give permission or not for the operation period to start. In case of a positive outcome in the respective city-council decision, the exact details for the area and time of operation and the operators (and respective documentation) that will man the remote control centre shall be provided to the local department of the ministry. In case all the prerequisites are met, the vehicle is granted with the same license plates that were provided during the testing period.

A last but important point is that having the vehicle granted with regular license plates, the problem of insurance is provisionally solved. The vehicle is being homologated according to the same rules as conventional vehicles (although specific special clauses apply), and insurance companies having a clear liability layout can (and have in our case) insure the vehicle.

5.3.4 HOW IT HAS WORKED IN PRACTICE?

From the aforementioned analysis, it is obvious that although a procedure is in place, this is far from being straightforward. In order to actually get clearance for a truly autonomous operation of an automated vehicle, one has to undergo through a lengthy process involving a number of stakeholders. It should be noted however that such a procedure needs to be in place and needs to be cumbersome (up to a point) to ensure that all safety and security measures are taking place to safeguard transport for all stakeholders. At the same time with a rather direct procedure, the liability actually remains the same as the 'driver' still exists in the operation phase but is simply removed from the vehicle (Figs 5.5 and 5.6).

In practice, the specific process has been put in place in the case of the CityMobil2 demonstration in Trikala. The final demonstration has changed in the meanwhile from small to large, meaning a larger fleet of six autonomous buses should be on operation for a period of around 6 months. The whole process was initiated with the infrastructure adaptation in late June 2015. The first set of vehicles was delivered to the city around July 2015. From that time and in conjunction with the technical setup (infrastructure, vehicles, mapping, etc.), the whole certification process started. As a result,

Fig. 5.5 Licensed CM2 vehicles at the Trikala opening ceremony.

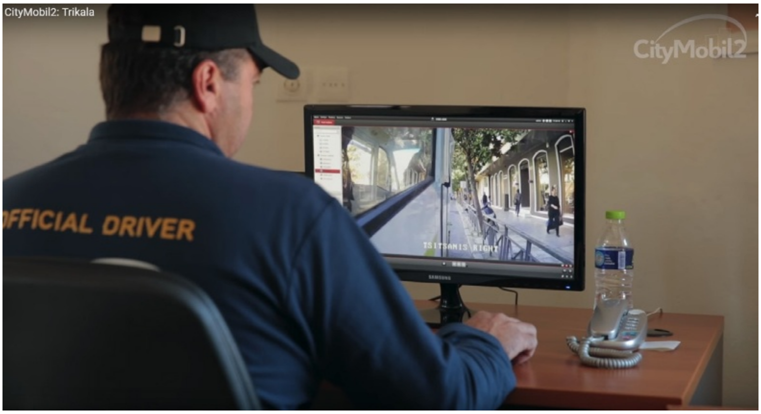

Fig. 5.6 The remote control centre during the Trikala CM2 demonstration.

it was approximately around mid-October where permission to start the testing period was granted. From mid-October to beginning of November, the buses were operating with an operator on board but without receiving passengers. The official inauguration ceremony for the demonstration was set on 10 November 2015. From that period on, the buses operated 5 days per week and for more than 6 h per day in accordance with the demand foreseen in the respective traffic study (Figs 5.7 and 5.8).

Fig. 5.7 Picture from the Trikala CM2 demonstration.

Fig. 5.8 Picture from the Trikala CM2 demonstration.

The tests that the vehicles had to undergo in order to get permission for autonomous operation were defined during December 2015 and have taken place in early January 2016. The vehicles have succeeded in all tests but one, which was due to a loss of GPS signalling in a specific part of the route. In order to cope with this anomaly, the local stakeholders decided to change the route for the last part of the demonstration and for a subset of vehicles. All tests have been repeated for the vehicles, and the new area of operation and all criteria have been met. Following the necessary steps, authorisation to pass the operation stage was granted mid-January, and two (out of the six) vehicles were operated autonomously till the end of February 2016.

Overall, the Trikala demonstration in numbers can be summarised as follows:

- 1490 is the number of itineraries carried out by the automated vehicles.
- 3580 km is the total distance travelled.
- 12,138 is the total number of passengers that were carried.

Last but not the least, it should be noted that during the entire demonstration, there was only one safety incident where the automated vehicle diverged from its trajectory making a slight turn to the right and crossing the pavement for approximately 50 cm with a velocity of less than 8 km/h. Fortunately, there was no accident, and neither any legal procedure has been initiated (although it would have been an actual crash test if such one would have taken place).

5.3.5 CONCLUSIONS AND DISCUSSION

For the question 'is autonomous driving legal in Greece', the answer is yes, but the procedure in order to get such an authorisation is lengthy and difficult. Still, the fact that the process has already been implemented once and for a 6-month-duration demonstration that yielded no actual problems for traffic safety is a positive sign. This is a strong point for further revisions to the legal process that may allow easier future implementations. Yet it should be noted that as dictated by the current law the operation of autonomous vehicles is allowed for a specific area of operation and for a limited period of time and only under the supervision of a public research or educational institute. These three constraints are rather restrictive for a future wide implementation of autonomous vehicles in Greece.

The biggest constraint however is the exact point that actually provided the way around the Geneva Convention. The law itself prescribes that the 'driver' can actually move away from the vehicle to a remote control centre as long as he/she has the same front, rear and side view around the vehicle as a driver of a conventional vehicle would have through the vehicle mirrors. Adding in our case, the in-vehicle camera that is able to monitor the status and number of passengers means that the remote operator shall have an overview of at least five camera views. That may be possible at low operational speeds and for a single match of a driver-operator. However, in a wider scale and attempting to put a fleet of vehicles in operation, the specific legal constraint (and having in mind that the remote operator bares the legal responsibility) makes it almost impossible without a group of operators (one per vehicle), making the whole process not cost-effective.

So, the current legal situation can only be considered as temporary. Truly, autonomous operation implies no driver on board nor a driver off board. Thus, we need to trust the technology in a wider sense in order to allow any possible legal constraint to be removed. On the other hand, the technology needs to prove itself in larger scale and real-context, whilst removing the remote operator will bring back the issue of liability. Maybe in this sense the Volvo solution in the Gothenburg large pilot (where the vehicle manufacturer assumes liability) is a way through. It is safe also to assume that regardless any national efforts the solution should be European. It makes no sense that the same vehicle for the same type of operation would undergo different procedures in different countries. The entire process would improve significantly if (at least some) common steps in the process could be identical (e.g. the vehicle mechanical parts, the surveillance requirements, the main authorisation body and the technical requirements). The process for achieving a European solution has started (e.g. GEAR 2030) but will be lengthy in time. Technology and advances on the other side of the Atlantic might prove to act as a catalyst.

Leaving aside future considerations and having in mind that for the time being the current law is in effect, there are two main issues that someone needs to take strongly into account for starting a similar demonstration: (i) all stakeholders need to be in line and motivated. The homologation process involves the municipality, the ministry, the traffic police department and in several points regional authorities. If even a single stakeholder is not in line, then significant delays might be created in the process that can make the operation practically unfeasible. Moreover, the general public should be well-informed and trained on how to behave around an autonomous vehicle. (ii) The initiator of such an operation should be bold. Regardless if the legal framework is in place and the liability issue is solved, nobody knows how the system will actually work in case of a serious incident. It is not far-reaching to assume that such an incident will have (if not legal) political or other implications for those that granted authorisation. But without a risk, no progress would be impossible.

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CHAPTER 6

CityMobil2 Impacts Seen from Outside

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CHAPTER 6.1

Successes and Shortcomings of the CityMobil2 Project as Seen From the Project Advisory Panel

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6.1.1 PROJECT GOALS

CityMobil2 was established as the culmination of an extensive sequence of European Commission-sponsored projects investigating the use of innovative automated road transport systems (ARTS) to improve urban mobility. As such, the emphasis of the project was on conducting practical real-world field tests in cities so that the barriers to implementation of ARTS could be identified and overcome on the ground in a diverse collection of European urban environments. More specific goals of the project were as follows:

Learning how to solve the practical problems involved in deploying and operating ARTS in cities

Promoting the awareness of the general public and public officials to the advantages of the ARTS

Creating a consistent legal framework for ARTS operations on the public road network

Implementation of large-scale pilot platforms (for technical and socio-economic tests and validation of ARTS in urban environments)

Providing ARTS technology capable of meeting the needs of public-transport operations

Assessment of reactions of the public to the availability of ARTS and their interactions with it in public service

Assessment of the wider socio-economic impacts of automated urban vehicles

Considering how ambitious these goals are, it should not be surprising that not all of them were completely accomplished.

6.1.2 SUCCESSES AND SHORTCOMINGS IN MEETING THESE GOALS

6.1.2.1 Learning How to Solve the Practical Problems Involved in Deploying and Operating ARTS in Cities

There are many practical problems associated with deploying and operating any urban public-transport system, but those are amplified when the system involves reliance on new and developing technologies. Each city tends to have unique institutional and physical characteristics, which makes it hard to generalise from experience in one city. This is a situation in which the large number of partner cities in CityMobil2 provided a great opportunity to learn from the diversity among those cities. The problems that they had to deal with included working within or changing regulations; obtaining the participation of all the relevant organisations, especially the local public-transportation operating organisations; developing the needed site-specific safety cases; and making suitable infrastructure modifications to accommodate the limitations of the vehicles.

At the institutional level, cities necessarily have to respect the current local and national regulations. Generally, these do not allow operation of ARTS on public roads. Cities have the power to modify their local regulations to allow the implementation of ARTS, but their decision-makers must first understand the function of ARTS and their technological limits. Only after having estimated the set of risks that a demonstration on a given route represents can a local, possibly temporary authorisation, be detailed and given. However, the main problem to solve concerns the respect for the traffic rules that, in the majority of the cases, are a national responsibility. It will thus be necessary that cities introduce a request for derogation from a higher institutional level, and it will certainly risk to be slow and maybe not easy to obtain.

At the end of the project, it is necessary to recognise that all the cities managed to resolve these institutional problems and to be ready in time for the on-site tests, which all took place without major incidents. For the future, it would be useful that these cities document and share their experiences in this domain to help other cities willing to introduce ARTS into their mobility plans.

At the organisational level, to facilitate ongoing use of ARTS, it is essential that cities involve from the beginning of the project the bodies that

will be responsible for the installation and the operation of ARTS in the future, generally the local public-transport operating companies. It will be advisable to convince these companies and their staff that ARTS are not rivals but that they are offering additional specific services to complement the classical public-transport systems. It will then be necessary to find the best way to proceed to these on-site demonstrations. These demonstrations will have to allow an operation of the system that has a sufficient size to show what problems will have to be solved for permanent and larger-scale implementations of ARTS. Any trial inevitably engenders temporary nuisances. To avoid any mortgage on the future deployment of ARTS in these cities' tests, it is essential to accurately inform the citizens of the advantages some stakeholders will gain from ARTS and to at least limit the inconveniences during the preparation of the infrastructure and during the trial itself. The biggest challenge will consist in solving all the technical, financial, administrative and legal problems in due course so that everything is ready when the infrastructure preparatory works start so that the site is ready on time for the beginning of the on-site trial.

All the cities' tests set up organisational systems adapted to their own environment. This set of experiences gained from the CityMobil2 trials should be gathered into 'instructions for use to implement ARTS' for other cities that would like to get started in this direction in the future. The current book can be considered as a first step in this direction.

It would be tempting to think that the use of automated vehicles in the urban transportation system could eliminate the human element in transportation operations, but the CityMobil2 experiences showed how untrue that is. The operations of the ARTS vehicles had to be closely coordinated with the local transportation agencies and the operating companies in each city. This was important not only for providing proper access to the main line-haul transportation services to support the goal of overcoming first-mile/last-mile access problems but also for dealing with more routine staffing challenges. The vehicles required on-board attendants ('grooms') to handle situations that exceeded the capabilities of the automation technology and central-office staffing to supervise operations (vehicle dispatching, coordination and maintenance). The logical way of implementing this was based on use of the existing capabilities of the local public-transport operators, which provided a good opportunity to educate these operating companies about the characteristics of the ARTS technology and vehicles. Indeed, the management of the operations of the fleet of ARTS vehicles was found to be a sufficiently interesting topic that

this aspect of the EPFL, Lausanne, demonstration led to the creation of a new start-up company, named BestMile, specialising in this type of work for other cities.

It would also be tempting to think that the automated vehicles should adapt themselves to the physical and operational characteristics of each urban environment in the same way that human drivers regularly do. However, the ARTS technology is not close to the level of maturity needed to accomplish that, so it needs help from the local infrastructure in order to achieve viable levels of operating speed and safety. One of the major accomplishments of CityMobil2 was the development of a process for assessing the safety of the vehicle operations, developing the safety case by assessing the possible hazards that the vehicles could encounter at every location along their intended routes. This assessment was used to set the maximum permissible vehicle operating speed at each location and identify the infrastructure modifications that would be needed to ensure safety at that speed, such as

- cooperative traffic-signal systems (communicating with the ARTS vehicles) to coordinate shared access at locations where the ARTS vehicles need to cross paths with conventional vehicles,
- special signage to alert drivers of other vehicles to be alert to the presence of the ARTS vehicles,
- removal of on-street parking along the vehicle route to eliminate the possibility for pedestrians to suddenly appear in the vehicle path with insufficient time for the vehicle to stop safely,
- installation of curbs blocking crossing paths for bicyclists to require the bicyclists to slow down sufficiently that the ARTS vehicle sensors have adequate time to detect them before they intrude into the path of the ARTS vehicle,
- suitable pavement markings to indicate the vehicle paths to pedestrians so that they are aware of the need to be alert about sharing that space with the vehicles.

General guidance about infrastructure requirements such as these is valuable information for other cities that are considering implementation of ARTS technology so that they can factor these issues into their plans and is an important contribution from the work of CityMobil2.

6.1.2.2 Promoting the Awareness of the General Public and the Public Officials to the Advantages of the ARTS

The implementation process of ARTS is very complex, especially in cities that have many actors with different needs and particularly when the technology is new and the legal framework is uncertain. For these reasons, it is

absolutely necessary to start the process of ARTS implementation in cities by promoting the awareness of the local stakeholders and the citizens.

Without well-targeted awareness campaigns, the CityMobil2 implementations of ARTS would probably not have had the success that they achieved. All the local authorities of the cities that participated in the project were convinced of the potential value of ARTS. They were also able to benefit from a better understanding of the way to implement ARTS in their cities. It is however necessary to point out that all these cities were already convinced to a certain extent of the interest in ARTS because they had decided to participate in this project and thus dedicate quite important financial and human resources to it. After they have run these systems for a few years and when they can establish a first balance sheet of their implementation, they will be able to share their experience with other cities and help them to go down that path and to have realistic expectations for what can be accomplished so that they are not disappointed.

Until the general 'instructions for use to implement ARTS' recommended above have been produced, cities who wish to implement ARTS should contact the cities that realised demonstrations to benefit from the lessons learned from their awareness campaigns.

6.1.2.3 Creating a Consistent Legal Framework for ARTS Operations on the Public Road Network

Existing legal frameworks, which do not allow highly automated vehicles on normal roads, are one of the main barriers hampering the deployment of ARTS. All the cities' tests succeeded to receive the legal authorisation or at least derogation, for their demonstrations, often after a continuous and in-depth dialogue with the national authorities or regulators.

To change the legal framework at the European level, CityMobil2 established a working group with scientists, system developers, cities and national certification authorities. This working group delivered a proposal for a European directive to set a common legal framework to certify ARTS. This proposal is based on a certification framework that includes seven main steps. Unfortunately, this procedure was only fully tested in one demonstration site, in Sophia Antipolis.

Since the beginning of the project, the legal situation of the ARTS has strongly evolved, and numerous countries have begun to take initiatives to legally authorise their implementation under some conditions. The CityMobil2-proposed framework should be tested against these fast-changing national initiatives (e.g. the United Kingdom, the Netherlands, Finland, Spain, Sweden and Greece).

6.1.2.4 Implementation of Large-Scale Pilot Platforms (for Technical and Socioeconomic Test and Validation of ARTS in Urban Environments)

The largest efforts within CityMobil2 were devoted to the field implementations of the ARTS systems in the host cities. These were largely successful through the heroic efforts of the project team, who had to overcome some severe challenges along the way. Some of the field implementations were tied to specific special events (such as the housing expo in Vantaa and the world expo in Milano), which led to hard schedule constraints on the ARTS implementations. In the case of Milano, problems with the larger preparations for the expo that were outside the control of the CityMobil2 team made it impossible to complete that pilot implementation.

By and large, the pilot platform implementations were successful in producing favourable publicity for the host cities and for the ARTS concept and vehicle systems. They were also a great learning experience for the project team, revealing the real-world challenges that will need to be resolved for more permanent future implementations. These involve considerations such as

– the importance of maintaining a strong central-fleet supervisory and monitoring function to handle unexpected events;
– the challenges involved in eventually removing the 'grooms' from the vehicles, based on the wide range of technical, operational and customer interaction issues that they had to handle;
– the need to educate the public thoroughly about the ARTS system before it is implemented so that the vehicle users and other road users develop correct mental models of the capabilities and limitations of the system so that they can interact effectively with it.

These field tests were not generally large enough nor did they last long enough to produce a validation of the technology or of its likely socio-economic impacts. It was probably unrealistic to expect such strong validation based on field implementations that could only last for several months and involve at most a half-dozen vehicles.

Ideally, the set of field trials would have tested performance in the full range of anticipated operating environments. A full set of ARTS attributes were identified, but the demonstrators were not able to assess some attributes, such as operation in snow and at low temperatures, competition with other modes and the imposition and collection of fares. Moreover, the impacts of some other attributes, such as operation in rain and fog and in differing street environments, were not always fully distinguished. It will be important to be clear as to the attributes that have not yet been fully tested, so that ARTS are not inadvertently introduced in circumstances in which they have not yet been tested.

6.1.2.5 Providing ARTS Technology Capable of Meeting the Needs of Public-Transport Operations

CityMobil2 was not intended to be a technology development project, but to rely on vehicle technologies that had already been developed by several private companies. The original plan was to choose vehicles competitively from among several potential suppliers. However, most of these suppliers ran into problems that rendered their vehicles unavailable for use in the project. In the end, only one vehicle technology was available for use, from Robosoft, although it was eventually supplied in two different vehicle packages, one directly from Robosoft and the other, more polished package, from EasyMile, a joint venture of Robosoft and Ligier. This imposed some serious limitations on the technological capabilities that could be applied to deliver the intended transportation services.

With the exception of the Vantaa demonstration, which was done on a protected right of way, the other demonstrations were severely limited in speed in order to maintain safety within the perceptual constraints of the vehicles' sensing systems. These very low speeds are probably not viable for commercial service except in very short-distance pedestrian-zone applications. The quality of service to passengers was also limited by the frequent false-positive obstacle detections, which caused frequent emergency-braking events, and by the timidity of the vehicles' automated manoeuvring, which led to other road users (drivers, bicyclists and pedestrians) taking advantage of them and blocking their motion. These problems are all consequences of the primitive sensing and sensor signal-processing capabilities of the vehicles, which need to be substantially improved before the vehicles can offer a service that is safe, comfortable, convenient and fast enough to be useful:

– Much better ability to discriminate between true obstacles in the path of the vehicle that need to be avoided and benign objects that should not interrupt the vehicle motion (dead leaves, bits of paper, etc.)
– Much better target tracking and target discrimination, so that trajectories of moving targets can be estimated to predict whether they are really likely to intersect the trajectory of the vehicle and require corrective actions by the vehicle
– Much more refined criteria for determining responses to targets detected by the vehicle, extending far beyond the two threshold distance criteria used by the vehicles that were tested (reduced speed at first threshold and hard braking at second threshold)

– Additional intelligence to permit vehicles some limited deviations from fixed routes when those routes are partially blocked by unexpected obstacles

There is also a need for careful exploration of the supervisory roles that can be played by the staff at the vehicle operation centre to reduce the importance of the 'grooms' riding along in the vehicles. At the current stage of development of the technology, human supervision remains essential to provide safety and quality of service, but it will not be economically viable to provide the intended type of flexible transportation service with small vehicles if every vehicle requires an on-board supervisor.

It was evident from the performance of the vehicles that were demonstrated that this goal of providing a technology with the ability to support a viable public-transportation service has not yet been achieved.

6.1.2.6 Assessment of Reactions of the Public to the Availability of ARTS and Their Interactions With it in Public Service

The reactions of the public were positive towards automated vehicles, and there was wide support for the implementation of automated vehicles in urban areas. The majority of the people surveyed believed that automated vehicles would be either safer than or as safe as human-driven vehicles except during night time. People experiencing the automated shuttles demonstrated in the cities were the most positive: they were satisfied with the service they experienced, and the most suitable role for them was seen to be providing feeder services to mass public transport. The most attractive benefit of ARTS would be reduced fares due to no driver costs.

We can consider that the city demonstrations were successful in terms of increasing awareness and understanding of ARTS and showing how automated vehicles can be used to provide public-transport services. However, sufficient evidence was not generated in the demonstrations to assess influences on mode choice and wider socio-economic impacts, in part because the ARTS were running at very low speeds and on very limited routes.

In practice, more could have been done. CityMobil2 had the advantage, by comparison with earlier studies, of having real-life demonstrators that could have been used as a basis for enhanced stated preference surveys to assess the likely impacts of ARTS when applied on a larger scale and in more realistic conditions. Such stated preference surveys could have taken the respondents' experiences of using the vehicle, in terms of

comfort, safety and convenience, as given, and set up, in an orthogonal design, sets of pairwise choices covering the main attributes expected to influence modal choice, including frequency, journey time and fare. Such stated preference surveys could, for example, have overcome the problem of limited speed by posing choices in which the ARTS vehicles run at expected operational speeds.

The ability of CityMobil2 to demonstrate its intended impacts on urban passenger transportation in the host cities was thus limited by the immaturity of the ARTS technology, the limited scale and duration of the demonstrations and the limited scope of the evaluation protocols adopted. The following considerations need to be kept in mind for the future:

– The usability by the public users and the potential transportation-system impacts were severely constrained by the technology limitations, limiting the speed with which the vehicles could operate on their intended routes. With the exception of the largely protected right of way in Vantaa, the interactions with other road users limited the effective speed to little more than walking speed, offering little practical advantage to users and lower interest to the commercial operators. The average speed of the ARTS should not be significantly lower than that of the existing local public-transport services: it is probably necessary to reach 10–15 km/h.
– Real public-transport services also need vehicles with sufficient passenger capacity, so some larger ARTS vehicles have to be tested.
– The frequent false-positive braking actions of the vehicles degraded the passenger experience and wasted travel time and energy. They are also a potential source of danger for the passengers who travel standing or seated without seat belts.
– An effective evaluation of the impacts of ARTS on urban passenger transport needs to identify the propensity of ARTS to attract patronage from cars and from walking and cycling, as well as from competing public-transport modes. Where, as seems likely in the near future, ARTS demonstrations are not of a sufficient scale to provide evidence from revealed preferences, greater use needs to be made of stated preference research, informed by respondents' experience of the ARTS vehicles being demonstrated.
– The attitudes of other road users towards ARTS also need to be understood better. These include the drivers of other vehicles who are sharing the road space with ARTS vehicles that may be significantly slower than their desired speeds and the bicyclists and pedestrians who may feel threatened by ARTS vehicles that they do not understand (and that are

not yet capable of communicating their perceptions and future actions to these vulnerable road users).

In the future, a comprehensive framework should be developed to support a wide range of evaluations including technical performance, practical safety assessment, user acceptance and impact assessment by monitoring attitude changes and mode-choice behaviour.

6.1.2.7 Assessment of Wider Socio-Economic Impacts of Automated Urban Vehicles

This broader goal was the most ambitious and difficult to achieve within the project plan. To achieve this goal, it would have been necessary to provide a comprehensive implementation of a full ARTS service in each of the host cities. In order to have measurable socio-economic impacts, such an implementation would have had to be

– based on fully mature vehicle technology capable of offering smooth, reliable service at a high enough operating speed to be a viable alternative to conventional technology transit services;
– of a large enough scale, with a large enough fleet of vehicles, to provide transportation service over a large enough area to be useful to a significant number of travellers;
– long enough in duration to have an influence on the trip-making decisions of travellers, as enough of them become familiar with ARTS to incorporate it into their regular travel, so that there could be some measurable 'before versus after' outcomes.

It is unrealistic to expect to see measurable socio-economic impacts from demonstrations of the scale that were possible within the CityMobil2 schedule and budget, but as noted in Section 6.2.6, more could have been done to assess their likely scale. This remains an area where further work is needed.

CHAPTER 6.2

Reviewing CityMobil2 for the European Commission

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6.2.1 THE 12 YEARS CityMobil EXPERIENCE AS INDEPENDENT EVALUATOR AND REVIEWER

Preliminary note: The review team involved several experts from different backgrounds. As an engineer for urban and regional planning with a special focus on transport strategies, it was my role in both projects to review the approach and usefulness of the project results in reference to mobility strategies—especially those laid out in European strategy documents (e.g. on SUMPs). Other reviewers worked on the system architecture and related technology questions.

When the first CityMobil project began, it was in a time before smart phones. The idea of autonomous transport was more science fiction for most people than a practical technological development for the coming decades. But in the meantime, new questions arose as practical applications of autonomous transport became more realistic and as smartphone apps brought new service models to transport.

Whereas CityMobil1 had three paths of technology applications (dual-mode buses, pods and cybercars), CityMobil2 focused from the outset on cybercar development and applications in small- and large-scale demonstrations.

For RTD projects in FP7, more resources were available for accompanying work by EU reviewers. As I have experience as coordinator of EU-funded transport projects, I was aware that such large projects may (and almost inevitably do) have unexpected developments and deviations and related formal and practical problems and conflicts. I understood my role as external EU reviewer to support the project in finding solutions (Fig. 6.1).

At the same time, I looked at answers to some questions that arose from the evaluation of the project proposal: what is the relation of these technologies to (mainly urban) transport? What potential is there to ease existing transport problems? How is the interaction with nonmotorised road users? Where and how can we integrate the technology into the existing urban fabric?

Fig. 6.1 EU officer and reviewers for CityMobil1 project in front of test vehicle.

All three modules of CityMobil1 make contributions and have their limitations and relevant insights for further development. The demonstration of dual-mode buses in daily operation with passengers in Castellón (Spain), where the bus was steered automatically (but with a driver in the seat), has a follow-up of sorts in the very recent presentation of an automatically steered bus in Amsterdam. In both cases, the driver is still in his or her seat, but there are already some advantages, such as more precise lane-keeping and a very precise approach to stops. In Castellón, the bus was programmed to leave a gap of only 40 mm. That, combined with a slightly elevated curb, creates a perfectly level access to the bus. But in both cases, segregated lanes are required.

The pod demonstration with well-designed automated vehicles on segregated, dedicated infrastructure (Heathrow airport) fits well in environments such as airports and peripheral business areas and industrial complexes but not in historically grown city centres. But looking at the experience with the vehicle size (designed as four-seaters) and acceptance by passengers, there may also be some lessons for the development of cybercars for the future.

The challenge of the cybercar development was clearly the operation in urban environments and interference with various other road users. The CityMobil demonstrations took place rather in partially segregated

situations or in pedestrian areas that, from the reviewer's perspective, raised the question of conflicts with pedestrians and cyclists and thus the potential of sustainable urban transport. The large-scale demonstration at the Rome trade fair area needed to be cancelled both because the entire demonstration was delayed and because the originally promised operation in a mixed environment with other road users was given up for completely segregated operation to serve the parking area.

CityMobil2 (2010–16) was not a continuation of the first CityMobil project but had, to some extent, other consortium partners and a clear focus on cybercar development and application (Fig. 6.2). Unfortunately, a demonstration of the entire fleet of the CityMobil2 vehicles during the 2014 World Expo in Milan—which was a highlight of the proposal—could not be realised.

As the technological progress allowed the project to prepare for demonstrations in the car lanes of public streets, the question of the legal licensing was an important module of CityMobil2. Already, the La Rochelle demonstration had some stretches where the route of the cybercar was in mixed operation with 'normal' cars plus cyclists and pedestrians. A crossing was done with signals as we know them from tram crossings. Still, most of the route was in pedestrianised areas (Fig. 6.3).

The demonstrations in Trikala (Greece) and San Sebastian (Spain) went a step further, as we could see operation in real life on mixed-used street space. Although you could still see the need for further technological development (e.g. when the sensors react to an overtaking car with an

Fig. 6.2 The CityMobil2 logo stick to a vehicle body.

Fig. 6.3 A bus stop in the CityMobil2 demonstration of Sophia Antipolis.

immediate stop), we came to a much more focused review on the potential and acceptance within urban mobility.

The main approach is on a 'last-mile service'. Different to heavily used PT lines, the first and last mile may require smaller vehicles as the capacity demand is lower. As a major expense for PT operators is labour costs (usually around 50 % of their costs), driverless vehicles are seen as a chance to increase frequency on the first/last mile. Such a scenario shows an improvement in the service quality of door-to-door public-transport chains, but one remaining core question for such scenarios is passenger acceptance of operation technically not only without a driver but also without a 'steward' on board. We all know how we feel in elevators with some unknown persons in a small cabin. Would this be accepted in an autonomous bus? Such an operating status is the precondition for reducing operating costs drastically and thus for increasing frequency of operation.

If one answer to this question is downsizing from a minibus (12–14 passengers) to a van (4–6 passengers), this would increase the number of vehicles in operation. And the nicely designed pod vehicles (as demonstrated within CityMobil1), with the features for autonomous cybercar, can be seen in operation to be demonstrated as autonomous road vehicles in London (2017).

Technically, it will be necessary to achieve higher operational speed. The CityMobil2 vehicles were not much faster than pedestrians and slower than cyclists. When riding autonomous vehicles (and this also applies to the 'Olli' in Berlin and to the 2016/2017 application of Navya minibuses

in Sion, Switzerland), there were many abrupt stops as the sensors sensed nonexistent obstacles.

To conclude, some technical development is still necessary. But CityMobil and CityMobil2 have paved some important parts of the longer way towards autonomous transport.

For the future, the relationship between autonomous road transport and sustainable urban mobility planning needs to be more in the centre of RTD projects, and municipalities and their transport planning experts should be more closely involved. The public transport of today may undergo some radical changes and it is crucial for cities to become aware and to get involved. It is necessary both to develop business models for integration into public-transport chains and to make the necessary connection to street design.

The European Commission drastically scaled down the role of external reviewers in RTD projects. There used to be resources for ongoing accompaniment of such development projects. It was a very synergetic idea of the CityMobil2 coordination to invite the reviewers to some of the project's thematic workshops, allowing them to keep track of and contribute to the project with relevant and timely questions.

Given the current media reflection on autonomous vehicles, the political discussion and some of the expectations, it would be good to build on the experience of CityMobil and CityMobil2. In the last 3 years, quite some development of legal frameworks has taken place—but still not usually using fully autonomous and driverless applications (i.e. without a steward) on public roads.

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IMPLEMENTING AUTOMATED ROAD TRANSPORT SYSTEMS IN URBAN SETTINGS

Edited by Adriano Alessandrini

Government officials, researchers, and transportation practitioners require real-world data and analysis in their efforts to bring automated and intelligent transport systems into the mainstream. *Implementing Automated Road Transport Systems in Urban Settings* provides the valuable, objective, often difficult-to-obtain data, gleaned from the largest demonstration project on automated road transport systems (ARTS) in the world to date.

The book features chapters authored by those deeply involved in CityMobil2—providing an easily accessible, cross-referenced resource for data and information on each aspect of the project. Chapters cover vehicle technical specifications, infrastructure analysis, operating systems, and future scenario analysis, as well as automated and conventional vehicle comparisons. *Implementing Automated Road Transport Systems in Urban Settings* examines the project's field tests, showing the technology's adaptability and different requirements based on geographic location. The book also explains the legal frameworks for system implementation.

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- Provides future ARTS scenario analysis, with information on planned, similar demonstrations.

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Adriano Alessandrini is Professor of Transportation Science and Economics at the University of Florence, in Florence, Italy. He coordinated CityMobil2, the world's largest project on integrating automated road transport systems in urban settings. Alessandrini has led many research projects on innovative transport systems, and on assessing the environmental impact of transportation. He has been published in many transportation-related journals, including Elsevier's *Transportation Research Procedia.*

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